PB 183513

Reproduced by the
CLEARINGHOUSE
for Federal Scientific & Technical
Information Springfield Va. 22151

APPLICABILITY OF ORGANIC LIQUIDS TO THE DEVELOPMENT OF NEW PROCESSES FOR REMOVING SULFUR DIOXIDE FROM FLUE GASES

FINAL PHASE I REPORT
UNDER CONTRACT PH 22-63-19

for

NEW PROCESS DEVELOPMENT SECTION
DIVISION OF PROCESS CONTROL ENGINEERING
NATIONAL AIR POLLUTION CONTROL ADMINISTRATION
PUBLIC HEALTH SERVICE
U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE

March 1969

BATTELLE MEMORIAL INSTITUTE
PACIFIC NORTHWEST LABORATORY
Richland, Washington 99352

Battelle is not engaged in research for advertising, sales promotion, or publicity, and this report may not be reproduced in full or in part for such purposes.

TABLE OF CONTENTS

LIST OF TABLES iv

INTRODUCTION 1

SUMMARY AND CONCLUSIONS 3

RECOMMENDATIONS 5

OBJECTIVE 5

SCOPE OF WORK 6

DISCUSSION 7

- Organic Liquids as Scrubbing Agents 7
  - Present Status 7
  - Reaction Mechanisms, Classes and Candidate Organics . 8
    - Symbols 9
    - Compilation of Equilibrium Data 9
    - Correlation of Activity Coefficients with Molecular Structure 10
    - Evaluation of Practical Utility of Liquids as SO_2 Absorbents 12
    - Dissociation Pressures of Solid Adducts of SO_2 and Organic Substances 13
  - Selection Criteria 13
    - Background Data 13
    - Availability and Cost 14
    - Physical and Chemical Properties 15
    - Conditions of Use 15
- Potential Sulfur Bearing Products 15
- Methods of Contacting Flue Gases with Scrubbing Agents . . 17
- Methods of Assuring Adequate Stack Plume Dispersion . . 18
- Organic Regeneration 19
- Applicability of Organic Liquids 22
  - General Considerations 23
  - Properties of Organic Liquids 25
  - Effects of Flue Gas Temperature 27
  - Oxidation and Degradation Effects 31
  - Solvent Emission Considerations 33
  - Solvent Availability 36

Most Promising Organic Liquids for Flue Gas Scrubbing 38

Application to Smelter Gas. 40

Preliminary Economic Comparison 41

Economic Bases 41

Adjustment of Alkalized Alumina Costs 47

DMA Process Comparison 50

Data Necessary for Assessment of Engineering and Economic Potential of Promising Candidates 52

Proposed Future Program 53

References 54

APPENDIX A A-1

APPENDIX B B-1

LIST OF TABLES

1	Activity Coefficients at Infinite Dilution - Low Values	11
2	Activity Coefficients at Infinite Dilution - High Values	12
3	Sulfur Dioxide Capacitiers of Liquid When Partial Pressure of SO_2 is 2.3 Torr	13
4	Dissociation Pressures of SO_2-Organic Adduct	14
5	Comparison of Organic Liquids Having Promising SO_2 Solubilities	26
6	Solvent Evaporation and Solvent Recovery Requirements	29
7	Solvent Recovery Requirements for 40 lb/day Solvent Emission	36
8	U.S. Production and Sales of Various Organic Liquids	37
9	Levelized Fixed Charges for Investor-Owned Utility	43
10	Wage Rates in Fossil-Fueled Power Plants	46
11	Adjusted Total Investment for Alkalized Alumina	48
12	Adjusted Annual Operating Cost for Alkalized Alumina	49
13	Approximate Chemical Costs of DMA Process for Flue Gas	52

PHASE I FINAL REPORT

APPLICABILITY OF ORGANIC LIQUIDS TO THE DEVELOPMENT OF NEW PROCESSES FOR REMOVING SULFUR DIOXIDE FROM FLUE GASES

INTRODUCTION

The two principal gaseous pollutants in urban and industrial atmospheres are automobile exhausts and sulfur oxides.(1) Air pollution by sulfur oxides, initially and mainly sulfur dioxide, is critical because of its damaging effects on plant life, impairment of air clarity, damage to structural materials via corrosion of metals, and deterioration of Portland cement, dimension stone, paper, leather and textiles. There is also, and more alarmingly, a strong correlation between human death rates and periods of heavy sulfur dioxide air pollution. These death rates are most significant among individuals with histories of respiratory, heart and circulatory disease, particularly infants and the elderly.(2)

The most prevalent source of sulfur dioxide air pollution is from the stack gas from thermoelectric power plants. These plants burn coal and petroleum fractions high in sulfur content. An increase in the amount of these fossil fuels burned for power can be expected to continue in the future. The critical dependence of the nation's total life and economy on a rapidly growing supply of electric power demands that all fuel resources be utilized. A large fraction of fossil fuel (coal) has a significant sulfur content.

The release of sulfur bearing waste gases also represents a loss of an otherwise very useful raw material, sulfur. This loss exceeds the amounts of sulfur produced in the U.S. from the usual sources. As power production increases, this source of air pollution will increase at even a greater rate because of the need to use lower grade or more available fuels of higher sulfur content. Other contributors to sulfur dioxide air pollution are major sources in some localities, but their total contribution is far less than that of the power plants. Smelters, petroleum refineries, pulp mills, sulfuric acid manufacturing plants, and other chemical industries are classic examples of such contributors.

There is no established technology today for assuring the efficient removal of sulfur dioxide from power plant stack gases without either imposing a severe economic burden on the industry or raising the pollution levels, for instance, of waste water or in the disposal of additional solid wastes.

In recognition of the seriousness and magnitude of the sulfur dioxide pollution problem, inherent in power plant stack gases, the National Air Pollution Control Administration has initiated support of a number of studies on the development of new processes for the removal of sulfur dioxide from industrial waste gases, specifically coal burning, power plant, stack gases. This report covers such a study made over the period of May 15 to December 13, 1968, as Contract No. PH 22-68-19.

SUMMARY AND CONCLUSIONS

The technology for the removal of sulfur dioxide from smelter gases by use of an organic liquid (dimethylaniline) is well established in the United States. Two large plants have been operating for about 20 years, one in California and one in Tennessee. No such technology, however, exists for similar treatment of thermal power plant (coal or oil fired) stack gases.

The magnitude of the engineering and economic factors for power plant stack gas treatment via organic liquids is enormously different from smelter gas treatment in volumes and composition of the gases to be handled, the effectiveness of SO_2 removal to meet allowable residual concentrations, and the critical dependence on extremely efficient recovery of the organic scrubbing agent.

Several prospective organic liquids have been noted. However, essential data which firmly suggest their applicability as suitable scrubbing agents are lacking. The classes of organic scrubbing agents include hydrocarbons (including olefins), esters, ethers, ketones, alcohols, amines, amides, nitro and sulfo compounds. Some candidates are 2,4-dimethylpyridine, N,N-dimethylaniline, triethanolamine, N,N-dimethylacetamide, and tetraethylene pentamine.

The most critical property of a candidate organic liquid sorbent which establishes its suitability for removal of SO_2 from power plant stack gases is its vapor pressure or volatility. In view of the enormous volumes of gas to be processed, and even at relatively low temperature, a material generally acceptable for its low vapor pressure could still be involved with intolerable economic losses because of volatility.

The candidate organic liquids, from an engineering or process standpoint, are sufficiently similar to enable the assessment of general applicability by study of any one on which the most data exist. Dimethylaniline and triethanolamine are typical candidates even though dimethylaniline has far too high a vapor pressure for power plant stack gas treatment.

Methods of contacting the gas with the scrubbing agent could be via venturi, cyclone, spray or grid systems. The grid systems are strongly preferred from the standpoints of cost and power requirements.

Thermal stripping is concluded to be the most acceptable method of regeneration. Reagents employed to form displacement compounds which, in turn, must be treated chemically to recover the organic agent appear to be too complex and costly. However, geographical considerations may necessitate conversion of the sulfur concentrate (SO_2) to a more marketable form such as elemental sulfur.

Cooling of stack gas will be required for any organic scrubbing process. If a visible steam plume is not tolerable, reheating will be required. However, adequate plume dispersion could probably be achieved without a major reheat requirement by increasing gas velocity in the stack.

The potential for increased pollution caused by injection of intolerable amounts of unrecovered sorbent into the atmosphere must be resolved for any organic scrubbing system. In addition, the potential operational hazards of flammability and explosiveness must be factored into the choice of an organic scrubbing agent.

From an optimistic viewpoint, given adequate equilibrium data with minimum sorbent degradation and minimum autocatalytic oxidation of SO_2 to SO_3 in the system, a process economically competitive with other scrubbing processes could probably be achieved by the use of rather conventional process equipment. Under such assumptions, problems of geography or environment and marketability of the recovered sulfur bearing product would be as important as the economy of the process in determining the choice of process and scrubbing agent. However, the obtaining of unfavorable data on sorbent degradation, SO_2 oxidation, or pollution aggravation by the release of objectionable quantities of the sorbent to the environment might require elimination of organic scrubbing as an applicable means in the development of processes for the removal of SO_2 from flue gases.

RECOMMENDATIONS

In order to achieve a realistic appraisal of the applicability of organic liquids as sorbents for SO_2 stack gases, experimental work in accordance with the following outline is suggested:

- Develop necessary equilibrium data for representative sorbents under flue gas compositions and conditions.
- Determine realistic vapor pressure and entrainment losses.
- Determine degradation or oxidation properties of representative sorbents.
- Determine the extent of autocatalytic oxidation of SO_2 to SO_3 in the sorbent system.
- Develop means for minimizing losses.
- Establish, in reactions common to the process, the role of the following major gas constituents: oxygen, nitrogen, nitrogen oxide, carbon dioxide, carbon monoxide, and sulfur trioxide.
- Develop the regeneration process.
- Establish the process flowsheet (material balance).
- Scout the applicability of likely sorbents selected on the basis of cost, availability, and desirable chemical, physical, and nonpollution properties, and possibilities for integration with the overall power plant function. Candidates might include polyethylene glycols, and the related amines, crude carbohydrates, and crude petroleum fractions (olefins).
- In this phase of the study, a critical evaluation should be made of the potential atmospheric pollution resulting from the use of organic scrubbing agents for SO_2 removal from industrial waste gases.

OBJECTIVE

The objective of this phase of the study was to survey the literature and, on the basis of findings, to assess the applicability of organic liquids to the development of new processes for removing sulfur dioxide from fossil fuel fired power plant stack gases.

SCOPE OF WORK

The literature search was made to establish the most promising classes of liquid organic compounds for sulfur dioxide removal and recovery. Individual compounds considered most promising were also identified.

The search also extended to the process engineering field to indicate the preferred methods of contacting the sorbent with the flue gas and the preferred technique of sorbent regeneration and recovery of sulfur values.

A preliminary assessment of the applicability of organic liquids for cleaning both smelter effluent and power plant flue gases was made, and conditions required to assure adequate effluent gas plume dispersion were reviewed.

Economic factors important to the comparison of organic liquids as scrubbing agents were reviewed, along with other means of sulfur dioxide removal. A compilation of pertinent literature references reviewed in the course of this study was completed and is attached as Appendix B to this report.

Experimental laboratory work to provide data required for adequate assessment of the engineering and economic potential of promising organic liquids is suggested.

DISCUSSION

ORGANIC LIQUIDS AS SCRUBBING AGENTS

Present Status

No evidence indicating the use of organic liquids on any scale for routinely removing the sulfur dioxide from power plant stack gases has been established. However, two sulfide ore smelters in the United States have been using dimethylaniline routinely on a large scale for about 20 years to scrub sulfur dioxide from a portion of their stack gases. The American Smelting and Refining Company plant at Selby, California(3) operates primarily on lead ores. The Tennessee Copper Company plant at Copper Hill, Tennessee, operates on both pyrite and copper ores. Both companies market the recovered product as liquid sulfur dioxide. In addition, both companies produce sulfuric acid from their stack gases.

In Germany,(3) xylidine (or toluidine) has been used as a scrubbing agent in one copper smelter and in one Portland cement--sulfuric acid--plant (via reduction of gypsum).

There are references to similar or modified applications of these organics to smelter stack gases in other countries, but the certainty of current commercial scale operations on a routine basis was not established.

Although no evidence of organic scrubbing of power plant stack gases has as yet been found, aqueous treatment has been applied in Europe. Air pollution abatement action against power plant stack effluents is just beginning in the United States. Controls thus far have been limited to specifying the sulfur content of fuels which are being consumed.

The enormous differences between the engineering and economic problems in the treatment of power plant stack gases, and problems in the treatment of smelter or chemical plant off gases should be acknowledged early in this study. Smelters generally release gases rich in sulfur dioxide and measuring several percent by volume. On the other hand, sulfur dioxide content in the effluent gases from the highest sulfur-type fuels burned by power plants should not exceed a few tenths of one percent. Whereas smelters or chemical plants may release gases at thousands of cubic feet per minute, the larger power plants may release millions of cubic feet per minute. The required dispersal of spent fumes from smelters via relatively small volumes from tall stacks is more assured than for power plants. The requirements for removing sulfur dioxide from stack gases thus can be expected to be more stringent for power plants than for smelters. The engineering, economics, and chemistry of power plant stack gas treatment therefore can not be viewed as simply a scale-up problem from smelter gas treatment technology. Instead, major problems are inherent in the assurance of the engineering performance of all of the processes and equipment, the guaranteed performance of the chemistry and kinetics of the process, and the economic penalties of off-standard efficiency. In addition, many organic agents which might be employed could introduce new pollution problems requiring solution.

Reaction Mechanisms, Classes and Candidate Organics

The SO_2 molecule has an O-S-O angle of 120°, S-O bond length of 1.43 Å, and dipole moment of 1.6×10^{-18} e.s.u. in the gas phase.(4) It is thus a small and strongly polarized molecule with a high positive charge density on the S atom not sterically protected by a surrounding shell of other atoms.

These features determine much of the chemical behavior of SO_2 with organic liquids. The exposed electrophilic S atom is attracted by nucleophilic centers in organic molecules, and its small size allows the SO_2 molecule to approach such centers closely if they are not sterically protected. Sulfur dioxide thus forms adducts with organic compounds containing O and N atoms possessing lone pairs of electrons. Such compounds include alcohols, ethers, aldehydes, ketones, esters, acid amides, and amines. Olefins and aromatic compounds, because of the pi electron cloud on the benzene ring, also form adducts with SO_2. The dissolution of SO_2 in liquids of these classes is due to adduct formation and, in some cases, precipitates of solid adducts can be obtained.

In systems containing H_2O as well as amines, SO_2 may react by a mechanism other than adduct formation, viz., by formation of sulfites:

$$2RNH_2 + H_2O + SO_2 \rightarrow 2RNH_3^+ + SO_3^{2-} + H^+$$

The small size of the SO_2 molecule also enables it to play the role of guest molecule in clathrate compounds. Hydroquinone, for instance, forms hydrogen-bonded crystals with a cage-like structure in whose vacant spaces SO_2 molecules can be trapped if they are present when the hydroquinone crystals are growing by precipitation from solution.

Symbols

The symbols to be used in the subsequent treatment are collected and defined here for reference:

A	Approximate activity coefficient of SO_2 in liquid at infinite dilution, $\lim_{x \to 0} \frac{P}{x}$
f	Fugacity of SO_2 in equilibrium with liquid
f°	Fugacity of SO_2 in standard state
n	Number of SO_2 molecules per organic molecule in adduct
r	Partial pressure of SO_2 in torr
P	Partial pressure of SO_2 in atm
t	Temperature, °C
w	Mass of SO_2 dissolved in mass 100 of solvent
x	Mole fraction of SO_2 in liquid

Compilation of Equilibrium Data

The abstracts collected in the literature search were scanned for references to SO_2 partial pressures in equilibrium with solutions of SO_2 in organic liquids. Most of the information gathered in this way was compiled in uniform format for easy comparison, and is contained in Appendix A. Information not included in Appendix A was rejected because of incomplete reporting of data, because the SO_2 partial pressures were far higher than those of interest in the present study, or because the liquids were much too volatile. Also, Appendix A does not contain data on mixed organic-aqueous absorbents.

The quantity A defined in the preceding list of symbols is useful for comparing the otherwise unwieldy collections of p-w-t data for different liquids. It is a close approximation to the activity coefficient of SO_2 in solution at infinite dilution. The exact definition of this activity coefficient is $f/xf°$. If the standard state of SO_2 is chosen to be the ideal gas at unit fugacity, the foregoing expression reduces to f/x which, in turn, tends to P/x as $P \to o$. Values of A were determined by plotting P/x against x and extrapolating the graphs to zero x.

Tables 1 and 2 show the values of A for compounds grouped according to molecular structure. Values of A less than unity at room temperature are listed in Table 1, those greater than unity in Table 2.

Correlation of Activity Coefficients with Molecular Structure

The smaller the value of A, the stronger is the affinity of a liquid for SO_2. According to the meager published data, the types of compounds listed in Table 1, particularly heterocyclic amines, show more promise as SO_2 absorbents than do those in Table 2. However, the compounds listed in Table 2 are too limited to allow the definite conclusion that their types do not include good SO_2 absorbents.

It is interesting to examine the effect on A of replacing H atoms by alkyl groups. For the series aniline, N-methylaniline N,N-dimethylaniline, for instance, the values of A at 25° are 0.41, 0.17, and 0.062. It is well known in organic chemistry that an alkyl group entering a molecule increases the electron density in the rest of a molecule by replacing hydrogen. The progressive decrease in A for 0, 1, 2 methyl groups on the N atom supports the view that the positively charged S atom of SO_2 is attracted by the negative charge on the N atom of the amine. For the series aniline, N-ethylaniline, N,N-diethylaniline, the values of A at 25° are 0.41, 0.29, and 0.8. The anomalously high value of A for N,N-diethylaniline may be due to partial steric blocking of the approach of SO_2 by the two ethyl groups. The pairs of compounds N,N-dimethylformamide, N,N-dimethylacetamide (A = 0.43, 0.11) and 2-methylpyridine, 2,4-dimethylpyridine (A = 0.08, 0.05) also show the expected effect of replacing H by CH_3.

TABLE 1. Activity Coefficients at Infinite Dilution - Low Values

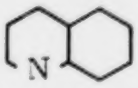
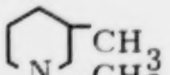
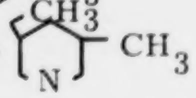
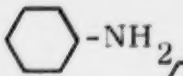
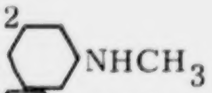
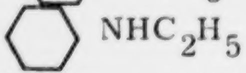
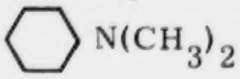
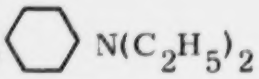
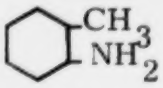
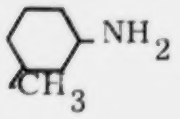
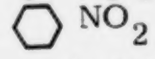
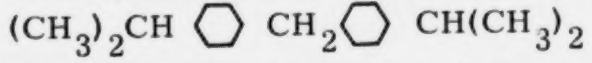
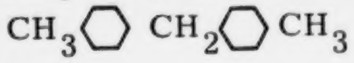
Compound Type	Compound	t	A
Substituted acid amide	N,N-Dimethylacetamide	25	0.11
	$CH_3CON(CH_3)_2$	38	0.24
		66	1.0
		93	2.8
	N,N-Dimethylformamide	25	0.43
	$HCON(CH_3)_2$	38	0.48
		66	0.80
		93	1.46
Sulfoxide	Dimethylsulfoxide $(CH_3)_2SO$	20	0.104
Ether	Tetraethylene glycol dimethyl ether	25	0.18
		38	0.38
	$CH_3OC_2H_4OC_2H_4OC_2H_4OC_2H_4OCH_3$	66	1.4
		93	3.5
Heterocyclic amine	Quinoline 	25	0.07
	2-Methylpyridine 	30	0.08
	2,4-Dimethylpyridine 	30	0.05
Aromatic amine	Aniline 	25	0.41
	N-Methylaniline 	25	0.17
	N-Ethylaniline 	25	0.29
	N,N-Dimethylaniline	15	0.02480
		20	0.03895
		25	0.061
		40	0.186
	N,N-Diethylaniline 	25	0.8
	1-Methylaniline 	25	0.4(4)
	2-Methylaniline 	15	0.17
		25	0.30

TABLE 2. Activity Coefficients at Infinite Dilution - High Values

Compound Type	Compound	t	A
Ketone	2-Octanone $CH_3CO(CH_2)_5CH_3$	25	2.0
Ester	Ethyl laurate $CH_3(CH_2)_{10}COOC_2H_5$	25	2.7
Alcohol	1-Heptanol $CH_3(CH_2)_5CH_2OH$	25	6.
Nitro compound	Nitrobenzene 	25	3.
Aromatic hydrocarbon	Dicumylmethane (mixture of isomers) 	25 40	1.7 2.8
	Ditolylmethane (mixture of isomers) 	25 40	1.7 2.3

The methyl group is only weakly electron donating in comparison with the OH and NH_2 groups.(5) If the foregoing interpretation of the effect on A of introducing CH_3 groups is correct, then the introduction of OH and NH_2 groups should strongly increase the SO_2 affinity of nucleophilic centers in organic molecules. This expectation is verified by results reported(6) for tetraethylenepentamine, triethanolamine, pentahydroxyethyl-diethylenetriamine, and hexahydroxyethyl-triethylenetetramine. Triethanolamine, for instance, with an A value of about 0.02 at 100°, indicates an enormously higher affinity for SO_2 than do the compounds in Table 1.

Evaluation of Practical Utility of Liquids as SO_2 Absorbents

A typical SO_2 content of 0.3% in boiler flue gas at 1 atm total pressure corresponds to 2.3 torr. For smelter off-gas, 3% is a typical SO_2 content, so that 90% removal of SO_2 from the gas would reduce the SO_2 partial pressure to 2.3 torr. The value of w in equilibrium with p = 2.3 torr is thus a rough practical measure of a liquid's utility as an SO_2 absorbent. Liquids with small values of A have been selected from Table 1 and listed in Table 3, together with values of w in equilibrium with r = 2.3 torr at the temperatures noted. These values of w were obtained from graphs P/x against x, or r against w. While these data provide a measure of an agent's capacity for SO_2 absorption, a much more rigorous engineering analysis of equilibrium data between gas inlet and exit conditions would be necessary to assess applicability of the agent for flue gas scrubbing.

TABLE 3. Sulfur Dioxide Capacities of Liquids When Partial Pressure of SO_2 is 2.3 Torr

Compound	t	w
N,N-Dimethylacetamide	25	1.8
Dimethylsulfoxide	20	2.4
Tetraethylene glycol dimethyl ether	25	0.5
Quinoline	25	1.9
2-Methylpyridine	30	2.5
2,4-Dimethylpyridine	30	2.9
N-Methylaniline	25	1.1
N,N-Dimethylaniline	25	2.5

Dissociation Pressures of Solid Adducts of SO_2 and Organic Substances

Table 4 shows the partial pressures of SO_2 in equilibrium with some solid adducts with organic substances. The organic compounds marked with asterisks are solid at room temperature. Their values of r are listed, but their adducts could possibly be prepared by precipitation from solution in organic liquids so that they fall within the scope of this study. Again, much more data, particularly equilibrium data in the inlet and exit range of conditions, are necessary to assess applicability of the agent for flue gas scrubbing.

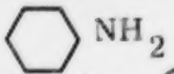
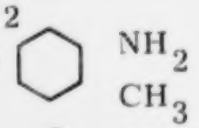
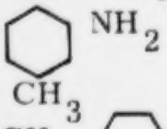
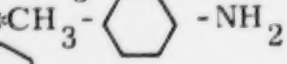
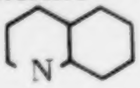
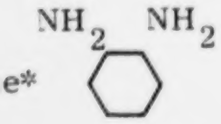
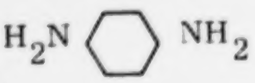
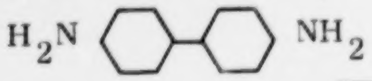
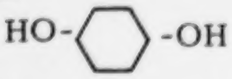
Selection Criteria

The following paragraphs highlight selection criteria which are reviewed in greater detail later on.

Background Data

It is concluded from data presented in the preceding section that not nearly enough information is available to make a firm selection of a candidate organic scrubbing agent. However, the available data do provide a starting point in indicating appreciable capability of certain agents or classes of organics for sulfur dioxide absorption, and that many form rather loosely bound compounds or adducts from which the SO_2 can probably be released by heating or steam stripping.

TABLE 4. Dissociation Pressures of SO_3-Organic Adduct

Compound	n	t	r	Ref
Aniline 	1	25	43.0	7
1-Methylaniline 	1	25	48.2	8
2-Methylaniline 	1	25	323	8
3-Methylaniline* 	1	20	11	8
Quinoline 	1	25	45	8
1,2-Diaminobenzene* 	1/2 1	25 25	4.0 17.0	8
1,4-Diaminobenzene* 	2	50	19.0	8
4,4^1-Diaminobiphenyl* 	2	25	6.0	8
Hydroquinone*† 	Unknown	25	3.8	9

---

*Solid at room temperature.
†SO_2 adduct is a clathrate.

Availability and Cost

Any extensive program of SO_2 removal from power plant flue gases might require several major additional production facilities to supply sufficient amounts of any organic material approved for use. It is even doubtful that adequate raw material supplies of many agents could be provided in the event of a concentrated demand by a substantial fraction of the power industry.

Coupled with this limitation is the obvious cost disadvantage. With few exceptions, most pure organics are costly. Most pure organics except for a few low molecular weight alcohols, the ketones, crude carbohydrates, fats, and crude petroleum fractions range well above 10 and even 20 cents a pound, with many well above a dollar a pound even in tank car quantities. The inventory requirements in such materials alone could range into millions of dollars of investment. It is also unlikely that the production of any nonvolatile pure organic, involving the introduction of special groups such as hydroxyl, amine, sulfur, or combinations of these, can ever be inexpensive regardless of production levels. These conclusions point to the requirement for a low cost material and for extremely low process losses.

Physical and Chemical Properties

An organic suitable for SO_2 scrubbing, aside from having good sorbent capacity for SO_2, must be extremely stable chemically in the environment of use. It must no degrade readily to nonreusable forms or form stable SO_2 complexes. In addition, if it is a liquid, it must stay as a liquid and not form solid intermediates. For reasons of economy and in order to simplify its recovery and reuse, its vapor pressure must be very low.

In addition to these physical and chemical property requirements, the organic agent must form adducts or compounds with SO_2 that are easily decomposed to yield the sulfur product in concentrated form and to yield regenerated organic at very high recoveries.

Conditions of Use

It is rather obvious that the selected organic agent should be compatible with the conditions under which it is to be used. The flue gas will contain oxygen, carbon dioxide, and carbon monoxide, as well as sulfur dioxide, sulfur trioxide, and nitrogen oxides as reactive components. Any of these could contribute to the irreversible degradation of the organic. Organics which could form explosive mixtures in a flue gas composition are, obviously, eliminated. Finally, in considering contributions of the organic agent or its degradation products to the overall pollution situation, any specific regulations applicable to the geographical area of use must be known.

POTENTIAL SULFUR BEARING PRODUCTS

There appear to be four saleable sulfur bearing products recoverable from power plant flue gases via organic scrubbing:

Sulfur Dioxide
Sulfur
Sulfuric Acid
Ammonium Sulfate

Geography as related to markets is probably the major factor in determining what product should be produced. Sulfur dioxide, although the easiest and probably the cheapest sulfur bearing product obtainable via organic scrubbing, has limited use at present prices. Sulfuric acid, perhaps the most useful product, is already quite inexpensive from usual sources, and thus cannot tolerate appreciable shipping costs from the producing plant to the customer. Elemental sulfur may be regarded as the preferred product. It is a solid of high purity and very stable under the simplest storage conditions, (usually outdoors unprotected from weather). Potential markets for sulfur, because of economical bulk handling in open railroad cars and barges, are not limited by shipping costs. Ammonium sulfate, an important material marketed worldwide as a bulk commodity, could be produced for sale as a fertilizer. Ammonia, however, would be required as an additional and costly raw material. The sulfate ion under some soil conditions is beneficial. In the form of ammonium sulfate, however, it serves principally as the means of providing a stable, solid, readily handled form of ammonia nitrogen. Other ions such as nitrate could also be used and, in many situations, with greater advantage. Thus ammonium sulfate is probably a desirable means of disposing of SO_2 but only under special circumstances which could limit its marketability.

Of the four potential products, elemental sulfur would be the most marketable and sulfur dioxide the easiest to produce.

The equivalent daily outputs and value (at current prices) of each of these potential products recoverable (at 90% yield) from the flue gas (0.3% SO_2) from a 1400 MW_e power plant would be about as follows:

800 tons SO_2	@	\$75/ton	= \$60,000/day
400 tons sulfur		\$37/ton	= \$14,800/day
1200 tons sulfuric acid		\$35/ton	= \$42,000/day
1650 tons ammonium sulfate		\$23/ton	= \$38,000/day

Elemental sulfur while representing the lowest value per day, is probably the only one of these potential products readily marketed from almost any location. A market for SO_2 at current prices and current high output does not seem possible. This product would have to be priced (on a delivered basis) at appreciably less than half the present price to make it competitive with elemental sulfur for sulfuric acid manufacture. Sulfuric acid would have to be priced to allow for shipping costs to make it competitive. Since two-thirds of the value of ammonium sulfate is represented by the ammonia content (at $60/ton), this product has the least value as an outlet for recovered sulfur.

The sulfur-bearing products marketable from a power plant flue gas treatment process thus can not be readily determined and will require a more detailed analysis.

METHODS OF CONTACTING FLUE GASES WITH SCRUBBING AGENTS

The major characteristic of any process for scrubbing power plant stack gases is the capability for handling high amounts of gas. Compared to normal petroleum and chemical industries, the contact required may be relatively incomplete. Major potential costs entailed in the scrubbing process itself include:

- Interest on the inventory of organic liquids required in the process.
- Organic losses resulting from degradation and volatility.
- Interest, depreciation, and maintenance on the scrubbing facility.
- Cost of operating pumps and fans.

The most economic methods of contacting would most likely be via various types of grid towers. Their higher power requirements limit consideration of Venturi and cyclone scrubbers. Performance data on the use of devices for scrubbing industrial boiler stack gases already exist. The pulp industry uses these and similar devices as "direct contact evaporators" where they concentrate an aqueous organic (black liquor) and, if operated correctly, scrub hydrogen sulfide out of the stack gas.

Aside from the volume of the flue gas to be handled, nothing particularly unique can be seen in the engineering of the flue gas contacting process.

METHODS OF ASSURING ADEQUATE STACK PLUME DISPERSION

Regardless of the method finally used to remove sulfur dioxide from power plant stack gases, the stripped gases must be released in a non-objectionable manner. Therefore, the plume itself must be adequately dispersed, i.e., mixed with environmental air, before contacting the ground. No foreseeable method of treatment could produce an effluent gas heavier than air. The worst conceivable case could produce a plume at 125 °F saturated with a density equivalent to that of dry air at 120 °F. Under these conditions, the plume would necessarily still rise. Use of a higher stack might be necessary in order to compensate for the loss of buoyancy, but the added height would not be more than about 5 stack diameters in the most severe cases.

The plume itself could cause a problem, however. Should the plume be discharged while saturated with water, a dense fog obscuring visibility and constituting a hazard to modern high speed travel, both surface and air, could result. Several methods for avoiding this problem seem to exist and a competitive evaluation of the alternatives would seem to be in order, possibly as a separate program.

Gas must be exhausted from the stack at a temperature substantially above its dew point to prevent the formation of dense fog. Possibilities include:

- Cooling the gas leaving the power plant through a second economiser before scrubbing the sulfur dioxide from it. The heat so collected could be used to reheat the scrubbed (therefore adiabatically saturated) gas prior to its release.
- Cooling the gas leaving the power plant before it enters the scrubbing system by using ambient air on the cool side of the economiser. The heated ambient air could then be mixed with the scrubbed stack gas prior to its release.
- Cooling the gas as described in the method immediately preceding, except that the heated ambient air and the scrubbed gas would be released in two concentric stacks with the heated ambient air in the annulus.

- Dehydration of the stack gas prior to release, e.g., by scrubbing with a hydroscopic liquid such as concentrated sulfuric acid.
- Reheating by direct flame.
- Reheating with steam coils using bleed steam from the turbines.

Other possibilities probably also exist. Of those methods listed, the first four would actually reduce the amount of water vapor released. The first three would reduce water vapor by lowering the temperature of the gas entering the adiabatic saturation (and scrubbing) section, while the fourth would remove water from the treated gas. Any of these operations, by reducing the amount of water to be dispersed, probably possess an inherent advantage over the last two. The relative merit of the alternatives, in order of preference, would appear to be the first, third or second, sixth or fourth, and fifth. However, some of these methods might be inexpensive and adequate in warm or dry areas of the country, while others would be more desirable in cool or damp areas. Some study of the effects of atmospheric conditions on plume dispersion has been done. However, little has been done to characterize the effect of plume modifications. Work in this area is needed and will be useful to all industry regardless of the methods chosen to remove SO_2 from power plant stack gases.

ORGANIC REGENERATION

There appears to be no possibility that the organic-sulfur dioxide combination produced from the stack gas scrubbing process might be salable as a valuable chemical. Thus, the organic must be recovered in a form suitable for reuse. Even a material available at a price as low as 5¢/lb (e.g., raw sugar) would be too expensive to use on a "once through" basis. Both the efficiency of recovery required and the cost of recovery allowed will vary with the costs of the rest of the process and the cost of the compound used. Heat, chemicals, or electricity are possible "ingredients" required by the recovery process.

Use of heat is potentially the cheapest means of recovery. Steam at 50¢ per million Btu's is approximately the cost of generation. Turbine bleed steam should be available at lower cost such as:

Steam at 150 psig (365 °F) = 25¢/10^6 Btu's
Steam at atmospheric pressure = 15¢/10^6 Btu's

Most organic liquids amenable to regeneration by heat would be regenerated by volatilizing a mixture of water and sulfur dioxide away from the organic, essentially a process of steam-stripping the organic. This could be done in a fractionation tower such as used in petroleum refineries to remove substantially all organic in the overhead and obtain the desired organic to water ratio in the regenerated liquid leaving the bottom of the tower. This approach would also serve to remove any volatile products produced by decomposition of the organic. These decomposition products could be forced out with the SO_2 and water leaving the top of the fractionating tower, although their removal as a liquid "side stream" should also be possible in most cases.

The organic may undergo some decomposition in both the scrubbing and regeneration sections. The decomposition products may constitute or may form volatile or nonvolatile materials or, more likely, both. They must, therefore, be removed. The volatiles will be treated as described in the foregoing if heat is used for regeneration. One obvious method of removing the nonvolatiles (tars) would be to evaporate a portion of one of the organic streams in an "agitated thin film evaporator" such as is used to evaporate paraffin from still bottoms in the petroleum industry. The vapor stream from this still could be passed into a fractionating column for removal of volatiles not automatically removed at some other part of the process. The decomposition products are presumed to be of no value and could be disposed of by burning along with the usual fuel.

The use of electricity to regenerate the organic is conceivable for some cases. The practical difficulties and the state of the art, however, mitigate against serious consideration of such processing. The state of the art is not generally well developed except for a few specific products. The application of electrical energy to chemical reactions is neither cheap nor efficient. The reduction of aluminum may be taken as an example. The power theoretically required is 2.3 kW-hr/lb, but operating plants actually required 10 kW-hr/lb. The cost of applying the 10 kW-hr/lb power is about 1¢/kW-hr plus the cost of the power itself.

The use of chemicals to regenerate the organic liquid is impaired by the low value of the sulfur which must be removed and the high cost of any reagents required. Although sulfur has increased in price lately and further increases are possible in the future, it is still a cheap, large volume, bulk material. For this reason, recovery of sulfur as a salable salt, a sulfate for instance, is limited to salts of very cheap cations, e.g., sodium or, possibly, ammonium. The advantage gained from sale of a more expensive salt would be more than offset by the cost of the cation required, regardless of form, and the expenses associated with losses and interest on inventory.

The use of sodium as a cation would be limited to regions having a good market for sodium sulfite, or sulfate and a plentiful cheap supply of some sodium salt of a cheap and basic anion, probably sodium carbonate (soda ash).

The major markets for sodium sulfate are the Kraft pulp industry, located in Washington, Oregon, Maine, and the south-eastern coastal states, and the synthetic detergent industry. The Kraft industry uses it as a makeup chemical and it could accept a crude sulfate-sulfite mixture. Unfortunately, the entire country uses only about 5000 tons per day. This market could be filled by the sulfur recovered from 4000 MW of coal fired electric power production. The synthetic detergent market, perhaps smaller in size, requires a clean, high quality sodium sulfate. The existence of adequate suppliers of high quality by-product sodium sulfate from a number of other industries does not indicate a strong possibility for beneficial disposal of recovered sulfur dioxide by this means.

Ammonium sulfate is also a possible product, although the ammonia in the product would be more valuable than the sulfur. Assuming the cost of ammonia can be borne and losses of ammonia minimized, the major problem would lie in producing a product capable of competing in the fertilizer market. Most of the sulfur, removable from the stack gas as a sulfite, would be converted completely to sulfate because the sulfite ion is poisonous to plants. If this difficulty could be overcome, the ammonium sulfate could be used as fertilizer in a world-wide market. Unfortunately, the high cost of the ammonia required for such production and the trend toward higher nitrogen concentrations in fertilizers mitigate against the economic production of this compound as the product.

Calcium sulfate (gypsum) from a chemical regeneration step is another product of very limited value. The "chemical" purchased would probably be calcium carbonate (limestone) and it would probably be used "as is", although it might be advantageous to convert it to quicklime or slaked lime before use. The calcium sulfite-sulfate mixture could probably not be sold. It is insoluble, however, and could probably be disposed of by dumping or used as land fill.

In summary, regeneration of the organic in a form suitable for reuse is mandatory and a heating process appears to be the best approach. In most cases the use of heat would recover the sulfur in a form amenable to conversion into elemental sulfur (or sulfuric acid, where there is a market). This approach is necessary because only the market for elemental sulfur appears large enough to accept the amount produced in the event a major fraction of the country's power industry were to convert to a sulfur recovery scheme. Elemental sulfur is also the easiest and cheapest material to transport and store.

If heat cannot be used, the use of limestone, with or without burning to quicklime, appears the only solution. The "product", mixed calcium sulfite-sulfate, would have to be dumped. Other materials could and might be used in specific instances. However, the market for sodium sulfate, for example, is small in respect to the total amount potentially available. The production of ammonium sulfate (fertilizer) of suitable quality involves major economic problems in use of large quantities of a costly raw material (ammonia) which must subsequently be marketed at a price permitting the recovery of raw material and processing costs.

APPLICABILITY OF ORGANIC LIQUIDS

The applicability of organic liquids to the removal of SO_2 from flue gases is explored in the following subsections. The use of organic liquids in general and the suitability of specific organic liquids are discussed in detail. Primary emphasis is on the use of organic liquids to remove SO_2 from the flue gases from fossil-fired power plants. The last subsection is devoted to SO_2 removal from smelter gases.

General Considerations

As discussed in earlier sections of this report, many organic liquids have the ability to remove SO_2 from flue gases. However, other physical properties and characteristics of organic liquids must be considered before applicability can be established. For example, most organic liquids have appreciable vapor pressures at desirable operating temperatures. Since most organic liquids are fairly costly, evaporation losses and recovery requirements must be considered. Also, many potential organic liquids are extremely toxic and odorous and these features make evaporation losses and recovery requirements even more important in determining the applicability of individual organic liquids. Other important considerations include the SO_2 loading, viscosity, oxidation or degradation losses, type of by-product, cost, and availability. Unfortunately, information on many of these items is not available for many organic liquids. However, available data on potential organic liquids are compared in subsequent subsections.

As has been stated earlier in this report, no process using an organic liquid to remove SO_2 from the flue gases from power plants was found during the course of this study. Two processes using organic liquids have been used to remove SO_2 from smelter and chemical processing gases. One process using anhydrous N,N-dimethylaniline (DMA) was developed by the American Smelting and Refining Company and is currently in use in this country.(10-12) The other process is called the Lurgi Sulphidine process and was developed and used in Germany.(10-11) The Lurgi process employs a suspension of xylidine or toludine in water. Neither process has ever been commercially used at the dilute SO_2 concentrations occurring in power plant flue gases. The dimethylaniline process operates on a smelter gas containing 4 to 6% SO_2, and the exit gas is discharged to the atmosphere at only about 0.05% SO_2. In both processes, a cold aqueous solution of dilute H_2SO_4 is used to recover organic vapors from the gases leaving the absorption towers. In both processes, the organic absorbent is regenerated by steam stripping. SO_2 is the recovered product. Either process may be applicable to removal of SO_2 from power plant flue gases. However, flue gas cooling and equipment for recovery of organic vapors from the flue gas would be required. Also, the literature on both processes refers to an autocatalytic oxidation of SO_2, especially at low concentrations. This phenomenon must be the subject of extensive laboratory investigation in any study of the applicability of these and other organic scrubbing agents.

A major example of the use of organic liquids to treat flue gases is the commerical recovery of CO_2 from combustion gases by the use of aqueous ethanolamine solutions. This process was developed in the early 1930's by the Girdler Corporation and is called the Girbotol process.(13-14) Currently, monoethanolamine is used in preference to either diethanolamine or triethanolamine, primarily because of its higher absorption capacity for CO_2. One objection to the use of ethanolamine solutions is their corrosiveness due to their oxidation to glycine and oxalic acid.(13) Monoethanolamine is much less susceptible to oxidation than the di- and tri-compounds. Also, data from existing plants indicate that monoethanolamine suffers degradation losses as a result of irreversible reactions with CO_2.(15) Study of the CO_2 degradation reactions shows no likelihood of similar reactions with triethanolamine. Other problems associated with the Girbotol process include fouling of solutions by sludge, foaming, and thiosulfate accumulation in solutions.(14)

The main purpose of mentioning the Girbotol process at this time is its importance in indicating potential problems for SO_2 absorption from combustion gases by organic liquids. For example, CO_2 is present in much greater quantities than SO_2 in combustion gases. The CO_2 could interfere with SO_2 absorption in some organic liquids and will absorb simultaneously with SO_2 in most organic liquids. Thus, the by-product could be contaminated with CO_2 or carbonates. Some organic liquids will suffer degradation losses from CO_2, SO_2, or oxides of nitrogen. Oxidation losses will also occur because of the oxygen in the combustion gases. Experimental data on CO_2 interference and on oxidation and degradation losses will be very important in assessing the potential of organic liquids.

Properties of Organic Liquids

Costs and various other characteristics of potential organic liquids are compared in Table 5. These items are important in comparing potential organic liquids and assessing the potential of each. Many of the probable reasons for the use of N,N-dimethylaniline (DMA) today for removing SO_2 from smelter gases are readily apparent. DMA has a lower cost than most other liquids in the table, has a reasonably high SO_2 capacity (at smelter gas concentrations), and can be easily regenerated. The vapor pressure of DMA is reasonably low at the temperatures of 20 to 25 °C employed in smelter gas treatment, and a salable product (SO_2) is recovered. A similar inspection of the tabulated information shows why xylidine and toluidine have been studied extensively and used in the Lurgi process.

The tabulated information can also be used to make a preliminary assessment of potential organic liquids for SO_2 absorption from combustion gases. Inspection of the vapor pressure data in Table 5 shows why triethanolamine (TEA) and tetraethylenepentamine (TEPA) have received considerable attention as potential organic liquids for high temperature absorption of SO_2 from combustion gases.(16) The low vapor pressure at high temperatures results in less evaporation of organic liquid during the absorption step, and in reduced requirements for recovery of organic vapors. However, other items in the tables, such as lack of a regeneration process and cost of TEPA indicate the need for much more experimental information before an accurate assessment of the potential of these two organics can be made.

In the absence of conclusive experimental data on the performance of organic liquids in combustion gases, many organic liquids exhibiting obviously poorer features or properties than DMA can be tentatively eliminated. DMA is a logical "base point", both because of the extensive information available and its use on smelter gases. Thus, many of the organic liquids in Table 5 can be tentatively classified as less promising than DMA by inspection of the boiling point, vapor pressure at various temperatures, cost, and SO_2 solubility.

TABLE 5. Comparison of Organic Liquids Having Promising SO_2 Solubilities

Compound	SO_2 Solubility,(1) g/100g solvent	Cost, $/lb	Boiling Point, °C	Approximate Vapor Pressure at 25 °C, mm Hg	Approximate Viscosity, centipoise	Regeneration Process
N, N-Dimethylaniline	2.5	0.22	194	0.6	1.28 (25 °C)	Heat
N-Methylaniline	1.1	0.70	196	0.4		(6)
N, N-Dimethylacetamide	1.8	0.40	166	0.9		(6)
Dimethylsulfoxide	2.4 (20 °C)	0.33	100 (d.)	0.6		(6)
Quinoline	1.9	0.50	237	1 (60 °C)		(6)
2-Methylpyridine	2.5 (30 °C)	(4)	128.8	11		(6)
2, 4-Dimethylpyridine	2.9 (30 °C)	(4)	159	3		(6)
Tetraethyleneglycoldimethyl ether	0.5	1.35	275.3	0.015	4.05 (20 °C)	(6)
Xylidine (mixed o, m, p)	~7 (20 °C)(2)	0.44	~220	0.35		
Toluidine (o-)	0.4	0.22	~200			Heat
Triethanolamine	N = 21.45(3) A = 42.9(3)	0.22	360	0.042	10.5 (100 °C)(5)	Not developed(7)
Tetraethylenepentamine	N = 86(3) A = 172	0.60	333	1 (151 °C)		Not developed

---

1. SO_2 solubility at 25 °C unless specified and at SO_2 partial pressure of 2.3 mm Hg in flue gas.
2. SO_2 solubility in 1:1 xylidine:water mixture.
3. Maximum solubility at equilibrium; N = neutral salt (amine:SO_2 = 2:1); A = acid salt (amine:SO_2 = 1:1).
4. Cost probably greater than pyridine. Refined pyridine (2° cut) costs 0.55/lb.
5. Viscosity without water dilution of triethanolamine.
6. Not fully defined but probably heat.
7. According to scouting experiments, regeneration by distillation with H_2SO_4 or by precipitation with lime slurry may be chemically feasible when SO_2 is absorbed at room temperature.

The tabulation of viscosity data in Table 5 can also aid in preliminary screening of potential liquids. Viscosity is an important property of the liquid phase in gas absorption. As the viscosity of the liquid phase increases, absorption efficiency tends to decrease because the greater viscosity means lower liquid diffusion coefficients and greater resistance to transfer in the liquid. Thus, higher viscosity tends to indicate more expensive gas absorption equipment and a greater hold-up of liquid absorbent in the equipment. For expensive organic liquids, increased liquid hold-up can be important. The high viscosity of tetraethylene glycol dimethyl ether is an additional drawback along with high cost and relatively low SO_2 solubility. In some cases, such as TEA, the high viscosity must be reduced by diluting the organic liquid with water or other low viscosity diluent. Dilution is most applicable to liquids with a high SO_2 solubility.

Effects of Flue Gas Temperature

A major reason for considering organic liquids has been the hope of developing a regenerative absorption process that does not require cooling of the flue gases. Elimination of stack gas cooling has been considered desirable (1) to avoid reheating the exit gas for improved buoyancy, and (2) to eliminate the water plume that could result from an aqueous scrubbing process. Unfortunately, most organic liquids exhibit appreciable vapor pressures at flue gas temperatures, and organic vapors are swept from the absorption equipment with the exit gas. These vapors must be recovered by other additional scrubbing processes because the cost or toxicity of the organic vapors would most likely be intolerable. Thus, the use of organic liquids probably will not eliminate the need for aqueous scrubbing of the flue gas. The ASARCO dimethylaniline process, the Lurgi process, and the Girbotol process all employ aqueous scrubbing to recover organic vapors from the exit gases.

The amount of organic vapor carried from the SO_2 absorption step is shown as a function of operating temperature in Table 6 for several organic liquids. The recovery efficiency required to reduce organic losses to 0.1 mill/kW-hr are also shown along with the amount of organic discharged after the organic recovery step. This information clearly shows the enormous quantity of organic vapor that must be recovered from high-temperature flue gas, and also shows the extremely high recovery efficiency that must be attained for most organic liquids in order to avoid major economic penalties. Values in Table 6 were calculated assuming a flue gas flow rate of 2.3×10^6 scfm from a 1400 MW_e power plant and a system pressure of 1 atm. The exit gas was also assumed to be saturated with organic vapor at equilibrium liquid temperatures of 77 and 200 °F at the gas-exit end of the SO_2 scrubber.

Of the organic liquids examined, evaporative losses and recovery requirements are lowest for TEA but recovery of TEA is still required at high temperature (200 °F). Recovery will probably be desirable if TEA is used at room temperature even though evaporative losses are fairly low.

As shown in data presented earlier in this report, the flue gas temperature affects the solubility of SO_2 in organic liquids that do not form a stable adduct with SO_2 at the temperature in question. As the temperature increases, the solubility of SO_2 in the organic liquid rapidly decreases. Unfortunately, little information is available on SO_2 solubility as a function of temperature. Available equilibrium data for several organic liquids are shown in Figure 1 as a function of temperature. These data show the equilibrium solubility when the SO_2 partial pressure is 2.3 mm Hg in the gas phase. The rapid decrease in SO_2 solubility at high temperature is clearly shown. In practical terms, this reduced solubility means much larger quantities of organic liquid and larger scrubbing equipment are required at higher temperatures. For example, from Figure 1 the solubility of SO_2 is 0.0011 mole SO_2/mole of N, N-dimethylacetamide at a temperature of 200 °F. Assuming this temperature and SO_2 loading for the exit liquid, the minimum possible liquid rate can be calculated from the inlet gas composition, gas flow rate, and degree of SO_2 removal. This minimum liquid rate is calculated to be 10.6×10^6 gal/hr assuming an inlet gas flow rate of 2.3×10^6 scfm, an inlet SO_2 concentration of 0.3 vol%, and a 90% removal of SO_2. In gas absorption, the actual liquor rate is usually greater than the minimum rate by 25 to 100%. However, the theoretical minimum liquid rate is convenient to use for a preliminary screening of potential solvents. The calculated minimum liquid rate is

TABLE 6. Solvent Evaporation and Solvent Recovery Requirements

Organic Liquid	Evaporation from Scrubber, 1000 lb/day		Efficiency Required in the Organic Recovery Section[3]		Solvent Loss Equal to 0. 1 mil./kW-hr, lb/day[1]
	77 °F[2]	200 °F[2]	77 °F	200 °F	
N, N-Dimethylaniline	872	41,600	98.2	99.96	15, 270
N-Methylaniline	514	31,500	99.0	99.98	4, 800
N, N-Dimethylacetamide	950	51,800	99.1	99.98	8, 400
Quinoline		9,790		99.93	6, 720
Tetraethyleneglycol-dimethylether	40	1,540	93.8	99.8	2, 490
Xylidine[4]	492	78,400	98.4	99.99	7, 640
Triethanolamine[5]	2	34.8	None	56.1	15, 270

---

1. For 1400 MW_e Power Plant.
2. Temperatures represent equilibrium liquid temperature at gas-exit end of SO_2 scrubber.
3. Required efficiency for 0. 1 mill/kW-hr solvent loss.
4. 1:1 xylidine: water mixture.
5. 20 wt% TEA in water.

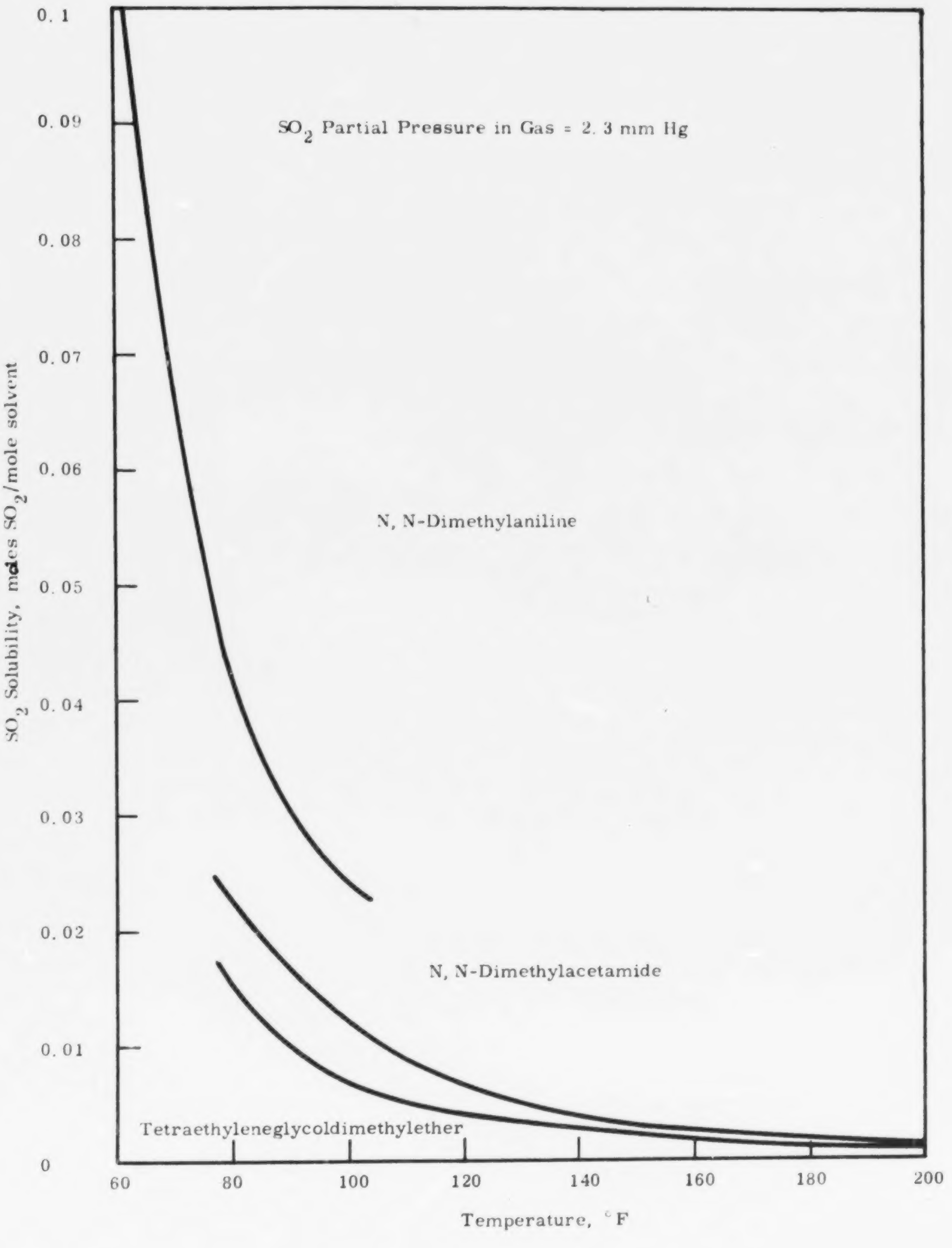


FIGURE 1. SO$_2$ Solubility as a Function of Temperature

impractical because of the large organic inventory and equipment required to accommodate such flows. Since most organic liquids follow the capacity trends in Figure 1, organic liquids that form stable adducts with SO_2 at high temperatures will probably be the only ones exhibiting adequate SO_2 capacities at high temperature.

Flue gas temperatures will also affect the degradation of the organic liquid in the scrubbing system. Degradation and the formation of corrosive degradation products will increase as temperatures are increased in the scrubbing and regeneration equipment. Degradation of organic liquids is so important that it is discussed separately in the following subsection.

Oxidation and Degradation Effects

Degradation of the organic liquid can result from oxidation, thermal decomposition at high temperature, or irreversible reactions with constituents of the flue gas. Unfortunately, little information is available on the rate of degradation of organic liquids at typical conditions for flue gas scrubbing. However, many organic compounds have an increased tendency to react with oxygen as the temperature is increased.

Available information on the oxidative degradation of monoethanolamine (MEA) in CO_2 scrubbers and solvent regenerators under conditions of nuclear submarine service provides some insight into the situation.(17) In this work, oxidative degradation of MEA was studied as a function of temperature under a variety of conditions. Experimental results showed that, in air containing 1% CO_2, oxidative degradation increased as temperature increased. Trace metal contaminants, such as copper, iron, nickel, and chromium, were found to catalyze the reaction. At 131 °F, tetrasodium-ethylenedinitrilotetraacetate (EDTA) was found to inhibit oxidation satisfactorily even in the presence of catalytic metals. At 208 °F with trace metals present, both EDTA and the monosodium salt of N, N-diethanologlycine (VFS) were needed for stabilization. Inhibitors were not effective at 280 and 300 °F with only limited amounts of oxygen present. On the basis of these results, exposure of MEA solutions to temperatures of 280 °F or above in scrubber equipment is feasible only if oxygen can be removed before exposure. Unfortunately, the limited amount of oxygen was not defined, but the inference of severe oxidation at high temperatures in the presence of oxygen is quite clear.

The experimental data on oxidative degradation of MEA are interesting to consider in terms of the large inventory or organic required for SO_2 removal from the flue gases of a large power plant. From the experimental data, the MEA oxidation rate at 208 °F, when no inhibitors or trace metals are present, is calculated to be 0.0002 lb MEA oxidized/hr/lb of MEA inventory. At this oxidation rate, an annual loss of 350,000 to 1,300,000 lb would be sustained by MEA inventories of 400,000 to 1,500,000 lb, respectively, if oxidizing conditions are encountered only half the time. These degradation rates are not directly applicable to TEA or other organic liquids used at high temperatures, but the potential magnitude of losses emphasizes the importance of laboratory experiments on oxidation rates and inhibitor requirements. Oxidation experiments on TEA are especially important since the literature states that TEA is much more susceptible than MEA to oxidation in combustion gases.(13)

Organic loss is not the only difficulty resulting from oxidative degradation. Organic degradation products are frequently corrosive to equipment, and these corrosive materials and trace metals from equipment corrosion must be removed from the organic liquid. In most cases, continuous distillation of a portion of the organic liquid will probably be required in addition to normal regeneration. Distillation is used to purify the ethanolamines when they are used to recover CO_2 from combustion gases. The distillation step not only increases equipment and operating costs but also provides another source of organic loss. These losses will occur as a result of organic solubility and entrainment when the residues from the still are discarded.

Degradation of MEA by CO_2 is an example of organic loss caused by irreversible reaction with one of the constituents of flue gas. MEA losses by CO_2 degradation have been reported by plants using MEA to remove CO_2 from hydrogen.(15) These losses are reported to be about 21 lb MEA/100,000 scf of CO_2 treated. For a 1400 MW_e power plant, this degradation loss would mean a MEA loss of about 30 x 10^6 lb/yr at a plant factor of 80%. This loss alone would eliminate MEA as a candidate for removing SO_2 from flue gas. Inspection of the degradation reactions for MEA shows that similar reactions will probably not occur with TEA; however, the magnitude of the MEA losses emphasizes the need for laboratory experiments on possible irreversible reactions between promising organic liquids and constituents in the flue gas. In this regard, further experimental work is needed on the irreversible reaction between SO_2 and any of the promising amines before their applicability can be established with certainty.

Solvent Emission Considerations

The control of solvent emissions is just starting to receive national attention,(18) with detailed surveys of solvent emission having been completed for the Los Angeles and San Francisco areas. Similar surveys have been underway in New York and Chicago but the results are not known. The Air Pollution Control Districts of Los Angeles County and the San Francisco Bay Area have been actively working for many years with the problems relating to solvent emissions. These efforts resulted in the passage of Rule 66 and 66.2 in Los Angeles in July, 1966, and in the passage of Rule 3 effective in the Bay Area in January, 1967.(19)

From an air pollution standpoint, the emission of organic vapors into the atmosphere is objectionable because of the photochemical reactions that can occur. Under the influence of sunlight, organic vapors react with oxygen ozone and nitric oxide to form ozone, aerosol particles (smog), and eye irritants such as aldehydes. Practically all organic vapors participate in these reactions, but some compounds are much more reactive than others.

The approach taken by Los Angeles and San Francisco to control solvent emissions has been to divide organic solvents into two classes based on susceptibility to photochemical smog-forming reactions. Although Rule 66 is very complex some basic provisions are briefly described in part as follows:

a. A person shall not discharge more than 15 pounds of organic materials into the atmosphere in any one day from any article, machine, equipment or other contrivance in which any organic solvent or any material containing organic solvent comes into contact with flame or is baked, heat-cured or heat-polymerized, in the presence of oxygen, unless all organic materials discharged from such article, machine, equipment or other contrivance have been reduced either by at least 85 percent overall or to not more than 15 pounds in any one day.

b. A person shall not discharge more than 40 pounds of organic material into the atmosphere in any one day from any article, machine, equipment or other contrivance used under conditions other than described in section (a) for employing, applying, evaporating or drying any photochemically reactive solvent or material containing such solvent, unless all organic materials discharged from such article, machine, equipment or other contrivance have been reduced either by at least 85 percent overall or to not more than 40 pounds in any one day.

c. For the purposes of this rule, a photochemically reactive solvent is any solvent with an aggregate of more than 20 percent of its total volume composed of the chemical compounds classified below, or which exceeds any of the following individual percentage composition limitations, referred to the total volume of solvent:

- A combination of hydrocarbons, alcohols, aldehydes, esters, esters or ketones having an olefinic or cyclo-olefinic type of unsaturation: 5 percent;
- A combination of aromatic compounds with eight or more carbon atoms to tne molecule except etyhlbenzene: 8 percent;
- A combination of ethylbenzene, ketones having branched hydrocarbon structures, trichloroethylene or toluene: 20 percent.

Whenever any organic solvent or any constituent of an organic solvent may be classified from its chemical structure into more than one of the groups of organic compounds, it shall be considered as a member of the most reactive chemical group; that is, that group having the least allowable percent of the total volume of solvents.

Rule 66.2 applies to the disposal and evaporation of solvents. This rule is as follows:

> "A person shall not during any one day dispose of a total of more than 1-1/2 gallons of any photochemically reactive solvent or of any material containing more than 1-1/2 gallons of any such photochemically reactive solvent by any means which will permit the evaporation of such solvent into the atmosphere."

Presumably, all organic solvents are photochemically reactive to some extent, so the differentiation between exempt and nonexempt solvents is a matter of judgement. The probable actions of other pollution authorities on adoption of solvent emission controls and on the concept of exempt and nonexempt solvents is not clear. In many cases, initial regulations will probably differentiate between solvents, but as the volume of organic vapors in the atmosphere increases, more and more solvents will probably have to be removed from exempt lists. Use of exempt solvents may be only an interim step in the advance toward more effective air pollution control.

The effect of solvent emission regulations on the use of organic liquids to remove SO_2 from flue gases is not known. Also, the degree of solvent removal that will represent compliance to the regulations is not clear. According to the Los Angeles regulations, DMA appears to be nonexempt from emission controls while TEA appears to be exempt. Table 7 shows the recovery efficiency required at several temperatures for recovery of DMA or TEA vapors from flue gas leaving the SO_2 scrubber if a solvent emission rate of only 40 lb/day is desired. Values in Table 7 were calculated by assuming a flue gas flow rate of 2.3×10^6 scfm and a saturation of the exit gas with organic vapor at an equilibrium liquid temperature of 77 and 200 °F. Anhydrous DMA and a 20 wt% TEA-water solution were also assumed.

TABLE 7. Solvent Recovery Requirements for 40 lb/day Solvent Emission[(a)]

Temp, °F	Evaporation from Scrubber, 1000 lb/Day		Required Recovery Efficiency, %	
	DMA	TEA	DMA	TEA
77	872	2	99.995	98.1
200	41,600	34.8	99.9999	99.88

---

a. From a 1400 MW_e power plant.

The tabulated values show the spectacular difference between recovery requirements for DMA and TEA. This difference occurs because DMA has a higher vapor pressure than TEA. The table also shows that solvent removal requires much higher scrubber efficiencies than SO_2 removal. With the possible exception of TEA at 77 °F, the recovery efficiencies are obviously impractical for large scrubbers because the use of organic liquids for SO_2 removal could eliminate one pollution problem and create another.

Solvent Availability

Commercial availability is another point of comparison between organic liquids. Because of the large quantities of flue gas being treated, large inventories of organic liquid will be required. These inventories could range from 0.5 to 2 million pounds or more for large power plants of 1000 to 1400 MW_e.

Some organic liquids are produced in much lower quantities or are available in much lower quantities from raw materials than others. The raw materials for most organic chemicals are coal, crude petroleum, natural gas, and certain other natural materials such as vegetable oils, fats, rosin, and grains. Crude organic chemicals are derived from coal by thermal decomposition, from petroleum or natural gas by catalytic cracking and by distillation or absorption, and from other natural sources by steps such as fermentation. Production of these crude organic chemicals is the first step in the manufacture of synthetic organic chemicals. From the crude chemicals, intermediate chemicals are obtained by synthesis or refining and are then converted to finished chemical products. Usually, more than half the total production of intermediates is used to produce other compounds. Many of the cyclic compounds listed earlier in Table 1 are classified as cyclic intermediates by the organic chemical industry. For example, over 50% of the N, N-dimethylaniline production is used in the production of other chemicals.

Table 8 shows U.S. production and sales of various potential organic liquids.(20,21) The differences between production and sales generally represent the amount used in the manufacture of other chemicals and finished products.

TABLE 8. U.S. Production and Sales of Various Organic Liquids[(a)]

Organic Liquid	Production, 1000 lb	Sales, 1000 lb
N, N-dimethylaniline	10,855	4,901
Quinoline	637	519
Pyridine (2° cut)	5,503	--
Pyridine Crude Bases (dry basis)	464,000 (gal)	--
Triethanolamine	48,130	46,839
Diethanolamine	65,521	49,043

---

a. Production and sales in 1964.

The low production of some organic liquids shows the importance of determining availability of any specific organic liquid under consideration. The availability problem is illustrated by the low production of pyridine crudes, most of which are derived as by-products from coal-coking processes. Thus, pyridine and pyridine-base compounds may not have the necessary availability at acceptable prices if demand far exceeds the amount available from the coal-coking processes. Also, since the low production rate makes the use of quinoline questionable, further study of the price-demand supply situation is needed for other promising organic liquids.

Most Promising Organic Liquids for Flue Gas Scrubbing

In the preceding subsections, the characteristics of potential organic liquids have been reviewed along with their effects in determining the suitability of an organic liquid for SO_2 removal from flue gas. These same properties can be used to provide a preliminary judgement of the applicability of organic liquids at various operating conditions.

When the applicability of organic liquids at various operating conditions is considered, it would be desirable to use organic liquids at low temperatures because of the detrimental effect of high temperatures on volatility or solvent emission potential, on SO_2 capacity, and on degradation potential. Presently, all of the organic liquids discussed in the previous subsections have one or more potentially severe difficulties at flue gas temperatures.

DMA was chosen here as a base-point for a preliminary screening of potential organic liquids. Only known properties or characteristics can be compared, and any unknown properties of DMA in flue gas service are assumed to be no worse than the other liquids being screened.

Dimethylacetamide, 2,4-dimethylpyridine, and 2-methylpyridine appear to be less promising than DMA because they are more expensive, more volatile, and have SO_2 solubilities comparable to or less than DMA. Quinoline and N-methylaniline appear less promising because of lower SO_2 solubility and higher cost. Pyridine derivatives and quinoline are also questionable because, without intolerable price increases, large quantities are not expected to be available. Dimethylsulfoxide costs more than DMA and has a low decomposition temperature. Tetraethyleneglycoldimethylether is five times more expensive, is more viscous, and has a much lower SO_2 solubility than DMA. Also, according to sales literature, this ether (like other ethers) undergoes autoxidation to form peroxides with light, heat, and oxygen promoting the reaction. Even though it has a much lower vapor pressure than DMA, requirements for vapor recovery from flue gas are still quite high because of the high cost and high molecular weight.

A clear-cut comparison of xylidine, toluidine and DMA cannot be made with the available data. Both DMA and xylidine have certain advantages. Essentially, anhydrous DMA is used to absorb SO_2; whereas, xylidine is used in a mixture of 50% xylidine in water, which has a higher SO_2 solubility than DMA at the low SO_2 concentrations of flue gas. Although xylidine has a slightly lower vapor pressure than DMA, this is not an advantage at high temperatures because of steam distillation effects. However, xylidine costs twice as much as DMA, and the solubility of DMA sulfate in water is much greater than that of xylidine sulfate. Therefore, the DMA sulfate concentration can be much greater than the xylidine sulfate concentration in the weak sulfuric acid solution used in the solvent recovery scrubbers, which results in a much lower water load on the regenerator.

During the absorption of SO_2 with either DMA or xylidine, the autocatalytic oxidation of SO_2 to SO_3 occurs. The amount of oxidation which is greater in a xylidine-water system, increases rapidly as the SO_2 concentration in the flue gas decreases. The greater autocatalytic oxidation and lower solubility of xylidine sulfate results in the need for more careful control of operating conditions when xylidine is used. Also, large amounts of water must be recycled to the regenerator to keep xylidine sulfate from precipitating and clogging the system. Experimental data on autocatalytic oxidation of SO_2 to SO_3 at flue gas conditions is needed to make a more precise comparison.

Toluidine could be more promising than xylidine because of the lower cost; however, SO_2 solubility in toluidine is much lower and the vapor pressure of toluidine is higher. Other definitive data at flue gas conditions are lacking.

A definitive comparison between TEA and DMA cannot be made at the present state of experimental data. Although the prices of TEA and DMA are the same, TEA apparently has a greater availability. Also, TEA has a higher SO_2 capacity and a much lower vapor pressure. TEA may be an exempt solvent; whereas, DMA apparently is a nonexempt solvent when applied to existing solvent emission regulations. Because TEA is used in a water solution, SO_2 removal with an aqueous TEA solution could result in a steam plume. The lower vapor pressure of TEA results in much less evaporation of solvent during the SO_2 absorption step and reduced requirements for recovery of organic vapors. TEA is a much more promising solvent than DMA when only these evaporation losses and solvent recovery requirements are considered. Unfortunately, a complete process is not yet available for TEA, nor is a regeneration step developed. However, scouting laboratory experiments have indicated that regeneration may be chemically feasible by distillation with H_2SO_4 or by precipitation with lime slurry.(16) Also, existing data indicate a problem with irreversible reactions between SO_2 and TEA, particularly at flue gas temperatures. Qualitative information on the use of ethanolamines to recover CO_2 from combustion gases indicates a potential oxidation problem for TEA. Experimental data are needed on these items before a definitive judgement on TEA can be made.

TEPA is in much the same category as TEA. TEPA has the advantage of a lower vapor pressure than TEA. However, the lack of a regeneration process and the cost indicate the need for more experimental data before an accurate assessment of TEPA can be made.

From the foregoing comparisons, DMA, xylidine, and TEA* appear to be the most promising of the organic liquids for which data are available. However, the extremely high scrubber efficiencies required for recovery of solvent vapors makes the use of DMA and xylidine very questionable. The comparisons also show some of the properties needed by any promising organic liquid for purposes of theoretical SO_2 solubility. Such promising, though untested, organic liquids should have a cost comparable to or not much greater than DMA, xylidine, or TEA. Also, the vapor pressure must be lower than DMA. Viscosity should be considered.

Application to Smelter Gas

Organic liquids are highly applicable to removal of SO_2 from smelter gases. The DMA scrubbing process is now used at two locations in the U.S. to remove and recover SO_2 from smelter gases while the Lurgi Sulphidine process is used in Europe. The lower gas flow rates from smelters may allow more flexibility in determining alternative solvents; however, present solvent emission regulations indicate the desirability of low vapor pressure. These regulations also indicate the potential advantages of replacing apparently nonexempt DMA with an exempt organic liquid.

---

* In view of data presented in Reference (16) (which was issued in the course of this present study) TEA itself is not a likely candidate. TEA must therefore be considered throughout this present report as a member of a class of compounds in which likely candidates may be developed.

TEA is promising for application to smelter gas if a satisfactory process can be developed. TEA may be an exempt solvent and the low evaporation from the SO_2 scrubber could result in reductions in capital and operating costs. In continued studies on this program, sorbents [other than TEA which does not appear clearly suitable in view of data presented in Reference (16)] which involve simpler and more economical processing than DMA for smelter gases could very likely be identified. Interest here may emphasize the development of a process based on an exempt solvent.(19)

PRELIMINARY ECONOMIC COMPARISON

Since no developed processes using organic liquids for SO_2 removal from power plant flue gases were found during the study, a detailed economic analysis cannot be made at this time. Experimental data are lacking for determination of realistic chemical flowsheets (material balances) and equipment requirements. However, the DMA process for smelter gas is well developed, and a preliminary comparison between some known features of this process in flue gas service and the alkalized alumina process can be made. To make the comparison, published economic information on the alkalized alumina process(22) was adjusted to reflect inflation and recently published economic bases for utilities. The adjustments mostly represent the economic bases proposed for the detailed Phase III study rather than any major disagreement with the published costs. The following subsections present the economic bases, adjustment of the costs for the alkalized alumina process, and a preliminary comparison with some known features of the DMA process.

Economic Bases

As in the economic study of the alkalized alumina process, the economic bases used for adjustment purposes apply to an investor-owned utility. Statistics published by the Federal Power Commission in 1964 showed that 76% of the generating capacity was investor-owned, 10% was publicly-owned (nonfederal), 13% was Federal-owned, and 1% was cooperative-owned.(23) Based on these percentages, fixed charges and other economic bases should be representative of an investor-owned electric utility.(24-26)

For investor-owned utilities, the return on investment is the average cost of money to the utility and is a composite of interest on debt (bonds), and earnings on equity (stock). The debt/equity ratio varies appreciably, but a 50/50 debt-equity ratio is not uncommon. The range of 40/60 to 60/40 probably includes most companies. Interest rates vary with the financial conditions of the country and the risk associated with investing in a particular company. In addition, the utilities use a variety of techniques to determine fixed charges, and they do not all incorporate the same components in their fixed charges. These different techniques do not result in grossly different fixed charges but do cause a rearrangement of the magnitude of some of the components.

Table 9 presents a tabulation of the fixed charges used in this study. This table presents fixed charges for an investor-owned utility for both the depreciating plant and the nondepreciating assets. The fixed charges for nondepreciating assets, such as land and working capital, differ primarily because they do not have the depreciation component; this, in turn, changes the magnitude of the income taxes. Although fixed charges on the depreciable plant are shown for three different plant lives to show the importance of this factor, a 30 year life is used in this study, with an assumed debt/equity ratio of 50/50. The bond interest and earnings on equity are assumed to be 5 and 8.5%, respectively, to give a composite rate of return of 6.75%. This return is in the upper range usually allowed for this regulated industry by utility rate commissions. A higher bond interest, similar to current interest rates, was not used because the current interest on utility bonds may only be a short-term peak. However, as bond interest goes up, earnings on equity decrease, or debt/equity ratio is reduced so that the composite rate of return remains essentially unchanged.

TABLE 9. Levelized Fixed Charges for Investor-Owned Utility

Component	Fixed Charge Rates, % of Initial Investment			
	Depreciating Plant			Nondepreciating Assets(a)
	10 yr life	30 yr life	45 yr life	
Return on Investment(a)	6.75	6.75	6.75	6.75
Depreciation (Sinking Fund)(b)	7.32	1.11	0.38	-
Federal Income Taxes(c)	1.07	1.49	1.79	3.92
Other Taxes(d)	2.0	2.0	2.0	2.0
Property Insurance	0.25	0.25	0.25	-
Interim Replacements	0.35	0.35	0.35	-
Total (rounded)	17.7	12.0	11.5	12.7

---

a. Primarily for land and working capital. If used for nondepreciating catalysts or chemicals add 0.25% for property insurance.

b. Constant debt/equity ratio of 50/50 assumed. Bond interest at 5%/yr; equity earnings at 8.5%/yr.

c. Plant life as specified in each column. Zero salvage value.

d. Federal income tax rate of 48% is assumed. SYD accelerated depreciation credit and 3% investment tax credit for first year are included. Tax life equal to book life.

e. Does not include gross revenue tax.

With the composite rate of return remaining constant, a slight shift in debt/equity ratio or rearrangement between bond interest and equity earnings will have only a slight effect on levelized fixed charges.

In the actual "book accounting" of a utility, investment in a depreciable plant is almost universally recovered over the book life by straight line depreciation. The net investment declines linearly, and the fixed charges--as a percent of initial investment--decline from year to year because the required return on investment is only charged against the undepreciated investment. Therefore, for engineering economy studies of utility alternatives, a "levelized" fixed charge value--as a percent of initial investment--is commonly used. This levelized fixed charge accounts for not only the year-by-year changes but for also the time value of money (present worth). A standard technique for calculating the levelized annual return plus depreciation is to use the required return on investment in conjunction with a sinking fund factor for depreciation.(24,27) This technique is used in Table 9.

Another method is to use straight line depreciation and a "levelized" return on investment. This levelized return is a present-worth average of the year-to-year return (on undepreciated investment) computed as a percent of initial investment. The methods are equivalent in terms of the sum of return plus depreciation, but the method used in Table 9 is more commonly used.

A levelized federal income tax on equity earnings is used in Table 9. This levelized tax, as a percent of initial investment, is calculated by use of the equity portion of the levelized return on investment. The sum-of-years-digits (SYD) method of calculating accelerated depreciation for tax purposes was used in determining the income tax in Table 9. Either the SYD or the double-declining-balance method has been used by investor-owned utilities since 1954. The federal income tax rate is assumed to be 48% since the future of the surtax is uncertain. The federal investment tax credit of 3% on the first year has also been included.

There are a variety of other taxes, besides federal income taxes, that are encountered by utilities, with local property taxes the most important. Some states have income taxes and franchise taxes and there are also gross revenue or gross receipts taxes; however, since gross revenue taxes must also be added to operating costs in economic studies, they are commonly added to the total annual expense rather than individually to the annual fixed charges and operating costs. The total of other taxes, as a percent of initial investment, can range from less than 2 to over 4%, depending upon the location. Economic studies of various utility alternatives usually use 2 to 3% for other taxes.(24) From these studies and other tabulated costs(23,26) encountered by utilities, 2% is used in Table 9 for other taxes.

A value of 0.25% is used for insurance in Table 9 and is commonly used in economic studies of utility alternatives.(24)

A value of 0.35% is used for interim replacements. This charge represents large expenditures for replacing major equipment components where failure of such equipment would impair the integrity of the asset during its life. As used here, this charge does not affect normal maintenance costs. Some utilities do not include this component in their fixed charges because of the excellent performance of modern fossil-fired power plants. Interim replacement is routinely used as a component of fixed charges in economic studies of chemical processing plants and seems appropriate here for the chemical processing equipment for SO_2 removal, especially since fixed charges equivalent to a 30-year book and tax life are assumed.

A depreciation time of 30 years is assumed for several reasons. The utility industry routinely uses 30 to 35 years for fossil-fired plants, and the same book life is commonly used for all parts of the depreciating plant. When a short book life is used by the chemical processing industry and a short tax life, such as 10 years, is allowed by the IRS, the short lives are usually in recognition of rapid obsolescence of the product and/or process in an extremely competitive industry. Such recognition may or may not occur in this instance. Electricity will not become obsolete, and obsolescence (if any) of a process for treating a waste stream may not be overly significant to utilities whose allowable return on investment and electricity rates are carefully controlled by regulatory agencies. However, a short tax life or special tax credits may be allowed to reduce the burden of pollution treatment on electricity rate structures.

A shorter book life, such as 10 years, could result in fixed charges that are difficult to absorb in the electricity rate structure. In actuality, the book and tax life will be established by the utilities after negotiations with the Internal Revenue Service, Federal Power Commission, and State Public Utility Commissions. In any event, a 30-year book life for equipment should be used only in conjunction with the interim replacement component in the fixed charges to provide for major equipment replacements resulting from failures or process improvements.

For purposes of this preliminary study, the alkalized alumina catalyst was capitalized and added to the plant investment as was done in the published evaluation of the alkalized alumina process. For a precise detailed comparison of alternative processes, inclusion of the initial cost of expensive catalysts or chemicals in the plant investment may not be proper. For example, a recoverable platinum catalyst will probably be a nondepreciating asset like land or working capital. Other catalysts or chemicals can have a salvage value or a shorter life than the plant investment. Since any of these conditions will alter the fixed charges, the conditions and fixed charges must be determined individually for each case.

The direct labor rates used in this study were developed by escalation of tabulated wage rates from a study in 1966 on fossil-fueled plant costs.(24) Escalation was arbitrarily taken as 8%, or 4%/ yr for 2 years. Salary rates for some personnel categories are summarized in Table 10.

TABLE 10. Wage Rates in Fossil-Fueled Power Plants

Personnel	Reference 1966 Salary, $/yr	Escalated 1968 Salary, $/yr
Plant Superintendent	$15,600	$16,800
Shift Supervisor	9,000	9,700
Control Room Operator	8,000	8,600
Equipment Operator	7,200	7,780
Utility Man	6,660	7,190
Relief	5,200	5,600
Mechanic	7,280	7,860
Electrician	7,280	7,860

A payroll burden of 30%, also listed in the 1966 study of fossil-fueled plant costs, was used in this study.

Interest during construction was taken as 6.75% of the cost of the gas scrubbing equipment, assuming installation along with a new power plant. Prior to the recent surge in interest rates, interest during construction has usually been calculated by utilities on the basis of 5 or 6% interest, with payment assumed during construction. The interest during construction is assumed to apply to the total construction cost for 45% of the design and construction period. The 45% is a standard factor in engineering economy studies and is based on the classical sigmoid curve for construction costs. Design and construction time is generally taken as 3 to 4 years. The 6.75% used in this study was calculated by assuming an interest rate of 5%/yr and a design and construction period of 3 years. A higher interest rate, similar to the current prime interest rate, was not used because the current rates may only be short-term peak rates.

For purposes of this study, working capital was not added to the plant investment but was handled separately. Annual costs for working capital were calculated from the levelized fixed charges in Table 9 for a nondepreciating asset. This method of handling fixed charges on working capital is generally used by the utilities.

A plant capacity factor of 90%, used in the published study of the alkalized alumina process, was used in this study for simplification, but this value is probably slightly high. Detailed studies of new fossil-fired plants indicate that the average lifetime capacity factor is likely to be only 60 to 70% because such plants will be part of the baseload portion of the system for only the first 10 to 15 years of life.(24) For evaluation purposes, an average lifetime capacity factor of 80% is commonly used.

Adjustment of Alkalized Alumina Costs

Adjustments of the published costs were primarily made by escalating the total plant cost by 8%, or 4%/yr for two years, and by incorporating the economic bases described in the preceding subsection. The published plant cost was assumed to contain the usual indirect construction costs, start-up costs, and contingency factor. The study assumed 0.2 vol% SO_2 in the inlet gas. Costs were not adjusted for this factor (SO_2 concentration) because details were lacking on the effect. Labor requirements and various percentages for labor and maintenance supervision, operating supplies, maintenance materials, spare parts, and indirect cost were not changed. Unit costs for coal, power, heat, and water were not changed, but alkalized alumina costs were escalated by 8%. The published construction costs were estimated on the basis of an addition to an existing plant. Some savings would probably occur if the unit was a part of a completely new plant; however, no adjustment was included in this study. The various categories of working capital were not changed, and the gross revenue tax was not added to the annual operating cost.

The adjusted total investment and annual operating cost are shown in Tables 11 and 12, respectively. These estimated costs are for a unit capable of removing 90% of the SO_2 from 87.3×10^6 scfh in an 800 MW_e power plant operating at an operating efficiency of 90%.

TABLE 11. Adjusted Total Investment for Alkalized Alumina

Item	Cost, $
Total Construction Cost	$8,000,000
Initial Catalyst Cost	369,000
Total Plant	$8,369,000
Interest During Construction	565,000
Subtotal for Depreciation	$8,934,000
Working Capital	642,000
Total Investment	$9,576,000 ($12/kW)

TABLE 12. Adjusted Annual Operating Cost for Alkalized Alumina

Item	Cost, $/yr
Direct Cost:	
Raw Materials and Utilities:	
Absorbent Makeup	$ 973,800
Coal for Producer Gas	475,200
Power	90,300
Heat	435,500
Water	26,000
Credit (Heat)	-311,100
Direct Labor:	
Operating	98,500
Supervision	14,800
Plant Maintenance:	
Maintenance Personnel	180,000
Supervision	36,000
Material	75,000
Payroll Overhead	99,000
Operating Supplies	58,000
Total Direct Cost	$2,251,000
Indirect Cost	231,000
Working Capital Charges	86,000
Fixed Charges on Plant	1,149,000
Total annual cost	$3,717,000
	(0.59 mills/kW-hr)

The adjusted total investment, including total plant cost, interest during construction, and working capital, is \$9,576,000 or \$12/kW. The adjusted operating cost is \$3,717,000/yr or 0.59 mill/kW-hr.

DMA Process Comparison

The DMA process has never been used for SO_2 removal from power plant flue gases so a precise definition of both the flowsheet and equipment requirements cannot be made. The chemical process will be nearly identical for SO_2 removal from either flue gas or smelter gas. Since essentially all chemical costs for the DMA process result from DMA losses or recovery of DMA vapors from the exit gas from the SO_2 scrubber, chemical costs can be readily developed for the use of DMA to remove SO_2 from flue gas. In view of the enormous quantities of DMA evaporated into flue gas, considerable insight on the applicability of the DMA process (and related processes) can be gained by comparing the annual chemical costs for the DMA process with the annual operating costs for the alkalized alumina process.

In the removal of SO_2 from smelter gas by DMA, the absorption tower is divided into three separate sections. Flue gas enters the bottom of the absorption tower and SO_2 is removed in the bottom section by counter-current contact with DMA. The flue gas containing some SO_2 and SMA leaves the bottom section and passes upward through the middle section where it is scrubbed with an aqueous 6% Na_2CO_3 solution. The Na_2CO_3 reacts with the residual SO_2 in the smelter gas as shown by the following reaction:

$$Na_2CO_3 + SO_2 \rightarrow Na_2SO_3 + CO_2$$

The gas leaves the middle section and passes through the top section where the gas is scrubbed with an aqueous 10% H_2SO_4 solution to recover the DMA vapors. The acid reacts with the DMA base to form DMA sulfate which is soluble in the scrubber water. The H_2SO_4 flow is adjusted so the acid is nearly saturated with DMA when it leaves the tower. The smelter gas leaves the top of the tower with only small amounts of wasted SO_2 and DMA.

The aqueous effluent from the middle section and top section flow to a collecting tank and are mixed. DMA is liberated as a result of the following reaction:

$$(DMAH)_2SO_4 + Na_2SO_3 \rightarrow 2DMA + Na_2SO_4 + SO_2 + H_2O$$

The mixture is then pumped to a gravity separator where DMA is removed and returned to the main supply. Part of the DMA remains dissolved in the water as DMA sulfite. The water, containing DMA sulfite and Na_2SO_4, first goes to the stripper water tank and then to the top tray of the regenerator where it is boiled vigorously. Any DMA sulfite dissolved in water is broken down into DMA and SO_2 which are carried by steam into the stripper and recovered. The aqueous Na_2SO_4 effluent from the regenerator is discarded to waste.

Some process changes would be required for DMA treatment of flue gas from a power plant. Because of the low SO_2 content and the large gas flow rate, there would not be enough residual SO_2 in the exit gas from the SO_2 scrubber to convert the necessary amount of Na_2CO_3 to Na_2SO_3. Thus, an aqueous Na_2CO_3 solution would probably have to be added to the receiver for the aqueous solution of DMA sulfate from the DMA recovery scrubber. The CO_2 would be removed and discharged to the stack with the exit flue gas. Should the use of Na_2CO_3 in this manner prove unsatisfactory, more expensive Na_2SO_3 would have to be used to react with DMA sulfate in the receiver. Alternatively, Na_2CO_3 and the aqueous solution of DMA sulfate could be added to the regenerator. The Na_2CO_3 would react with freed SO_2 to form Na_2SO_3 which would then react with the DMA sulfate to form DMA, Na_2SO_4, and SO_2. However, use of the regenerator for the reaction is unsatisfactory because the recovered SO_2 would be contaminated with CO_2.

The use of H_2SO_4 and Na_2CO_3 is carefully balanced to the amount of DMA vapor in the exit gas from the SO_2 scrubber. Therefore, the stoichiometric amounts of Na_2CO_3 and H_2SO_4 required in the preceding reactions are a fairly good approximation of chemical requirements for recovery of DMA vapor. For a system handling 87.3×10^6 scfh of flue gas from an 800 MW_e power plant, DMA evaporation from the SO_2 scrubber is calculated to be 181.3×10^6 lb/yr at an operating efficiency of 90%. This value was calculated by assuming the exit gas is saturated with vapor at an equilibrium DMA temperature of 77 °F. Assuming a fairly optimistic 98% recovery efficiency in the large scrubbers, DMA recovery is 177.7×10^6 lb/yr and the DMA loss to the stack is 3.6×10^6 lb/yr. On the basis of stoichiometric amounts of Na_2CO_3 and H_2SO_4, chemical costs are summarized in Table 13. Should Na_2SO_3 be required instead of Na_2CO_3, costs would be higher.

TABLE 13. Approximate Chemical Costs of DMA Process for Flue Gas[a]

Chemical	Unit Cost, $/lb	Annual Consumption, lb/yr	Annual Cost, $	Cost, mills/kW-hr
DMA	0.22	3.6×10^6	792,000	0.125
H_2SO_4	0.017	71.85×10^6	1,222,000	0.193
Na_2CO_3	0.016	77.7×10^6	1,243,000	0.197
Total			3,257,000	0.51

(a) For 800 MW_e power plant.

Comparison of these chemical costs with the total annual costs for the alkalized alumina process clearly shows the poor competitive position of the DMA process. The DMA process will not be competitive with the alkalized alumina process unless the degradation of alkalized alumina, the cost of alkalized alumina, and other estimated cost factors turn out to be significantly higher.

The chemical costs also show that further experimental work on organic liquids should be limited to liquids with vapor pressures much lower than DMA.

DATA NECESSARY FOR ASSESSMENT OF ENGINEERING AND ECONOMIC POTENTIAL OF PROMISING CANDIDATES

On the basis of vapor pressure losses tabulated in the previous section, few candidates hold much promise as applicable sorbents. The recovery of the volatilized sorbent--taking dimethylaniline as the example--will involve large daily tonnages of sulfuric acid and soda ash equivalent to the DMA recovered. The resulting dilute sodium sulfate must then also be disposed of without further contributing to environmental pollution. This can be done only by recovery as solids for sale as low valued salt cake. Extensive study should therefore be directed at other candidates of a class in which triethanolamine (TEA) is an example. Data required include the following:

- Determine degradation or oxidation properties of representative sorbents of the class of which TEA is an example.

- Determine the kinetics of autocatalytic oxidation of SO_2 to SO_3 in the sorbent system.
- Determine realistic vapor pressure and entrainment losses.
- Evaluate economical means of minimizing losses.
- Establish the conditions for an acceptable regeneration process.
- Develop necessary equilibrium data for representative sorbents under flue gas composition and conditions.
- Establish the process flowsheet and material balance.
- Scout the applicability of additional likely sorbents selected on the basis of cost, availability, and desirable chemical, physical, and nonpollution properties and possibilities for integration with the over-all power plant function. Candidates might include other fatty amines, polyethylene glycols and amine derivatives, crude carbohydrates and crude petroleum factions (heavy olefins).
- On this phase of the study, a critical evaluation should be made of the potential atmospheric pollution resulting from the use of likely liquid organic scrubbing agents for removal of SO_2 from industrial waste gases.

PROPOSED FUTURE PROGRAM

A program should be initiated to provide the data obtainable by doing the work outlined above. It is recommended that work on the first three items and the fifth be studied initially to be certain of the applicability of any specified agent. This program could place considerable emphasis on the selection of sorbents which can be expected to be classed as exempt under existing control regulations.(19) Attention should be placed on the prospects for developing such an absorbent to replace DMA in smelter off-gas processing.

REFERENCES

1. Ludwig, J. H. and Spaite, P. W.
CONTROL OF SULFUR OXIDES POLLUTION: THE CHALLENGE TO THE CHEMICAL ENGINEER.
A. I. CH. E, Detroit, Michigan.
(December 4-8, 1966)

2. U. S. Department of Health, Education and Welfare.
AIR QUALITY CRITERIA FOR SULFUR OXIDES.
Public Health Service Publication No. 1619 (March 1967)

3. Cole, R. J.,
THE REMOVAL OF SULPHUR GASES FROM SMELTER FUMES.
Report by Ontario Research Foundation, Toronto, Canada (1947)

4. Weast, R. C., ed. (Chemical Rubber Company, Cleveland)
HANDBOOK OF CHEMISTRY AND PHYSICS.
48th edition, pp. F-148, E-65. (1967)

5. Fieser, L. F. and M.
ADVANCED ORGANIC CHEMISTRY
Chapter 17, Reinhold, New York (1961)

6. Arthur D. Little, Inc.
THIRD MONTHLY PROGRESS REPORT ON CONTRACT PH 86-68-57
Table I (1968)

7. Hill, Arthur E.
REACTION OF AMINES WITH SULFUR DIOXIDE.
I. ANILINE AND SULFUR DIOXIDE.
J. Am. Chem. Soc. 53, 2598-2608 (1931)
CA 25, 4482

8. Hill, Arthur E., and Fitzgerald, Thomas B.
COMPOUNDS OF SULFUR DIOXIDE WITH VARIOUS AMINES.
J. Am. Chem. Soc. 57, 250-4 (1935)
CA 29, 1689

9. Wynne-Jones, W. F. K., and Anderson, A. R.
THE THERMODYNAMIC CONDITIONS FOR THE FORMATION AND THE EXISTENCE OF CLATHRATE COMPOUNDS.
Compt. Rend. Reunion Ann. Avec. Comm. Thermodynam.,
Union Intern. Phys. (Paris) 1952
DA 48, 34

10. Fleming, E. P. and Fitt, T. C.
LIQUID SULFUR DIOXIDE FROM WASTE SMELTER GASES.
Ind. Eng. Chem., vol. 42, no. 11, p. 2253 (November 1950)

11. Cole, R. J. (Ontario Research Foundation, Toronto, Canada)
THE REMOVAL OF SULFUR GASES FROM SMELTER FUMES.
1947

12. Anon.
HI-PURITY LIQUID SO_2
Chem. Eng., p. 274. (April 1953)

13. Shreve, R. N.
THE CHEMICAL PROCESS INDUSTRIES.
McGraw-Hill Book Company, Inc., New York, 2nd ed., pp. 131-132 (1956)

14. Updegrass, N. C. and Reed, R. M.
TWENTY-FIVE YEARS OF PROGRESS IN GAS PURIFICATION.
Petroleum Eng., vol. 26, pt. 3, p. C-57 (September 1954)

15. Berlie, E. M., Estep, J. W., and Ronicker, F. J.
PREVENTING MEA DEGRADATION.
Chem. Eng. Prog., vol. 61, no. 4, p. 82 (April 1965)

16. Beutner, H. P., Niesson, W. R., Haley, H. E., and Emerson, W. S.
FEASIBILITY OF A REGENERATIVE HIGH TEMPERATURE AMINE ABSORPTION PROCESS FOR THE CONTROL OF SULFUR DIOXIDE EMISSIONS FROM STACK GASES.
A. D. Little, Inc., New York (August 1968)

17. Blachly, C. H. and Ravner, H.
STABILIZATION OF MONOETHANOLAMINE SOLUTIONS IN CARBON DIOXIDE SCRUBBERS.
J. Chem. Eng. Data, vol. 11, no. 3, p. 401 (July 1966)

18. Cooper, J. C.
"Control of Solvent Emissions,"
NEW DEVELOPMENTS IN AIR POLLUTION CONTROL, PROCEEDINGS MECAR SYMPOSIUM NEW YORK, OCTOBER 23, 1967.
Metropolitan Engineers Council on Air Resources, New York (1967)

19. Anon.
A COMPILATION OF SELECTED AIR POLLUTION EMISSION CONTROL REGULATIONS AND ORDINANCES.
Public Health Serivce, U. S. Dept. of Health, Education and Welfare, Revised Edition, Washington (1968)

20. Anon.
SYNTHETIC ORGANIC CHEMICALS, U. S. PRODUCTION AND SALES, 1964.
TC Publication 167.
U. S. Tariff Commission, Washington (1965)

21. Manufacturing Chemists Assoc., Inc., Washington.
CHEMICAL STATISTICS HANDBOOK.
6th ed., (1966)

22. Katell, S.
REMOVING SULFUR DIOXIDE FROM FLUE GASES.
Chem. Eng. Progr., vol. 62, no. 10, p. 67 (October 1966)

23. Federal Power Commission, Washington, D. C.
NATIONAL POWER SURVEY.
October, 1964

24. Newbold, H. L. R. (Jackson & Moreland, Boston, Mass.).
COSTS OF LARGE FOSSIL FUEL FIRED POWER PLANTS.
J&M No. 636A, July 15, 1966

25. Geller, L., Hogerton, J. F., and Stoller, S. M.
ANALYZING POWER COSTS FOR NUCLEAR PLANTS.
Nucleonics, vol. 22, no. 7, p. 64 (July 1964)

26. Anon.
14th STEAM STATION COST SURVEY.
Electrical World, vol. 164, no. 16, pp. 103-18 (October 18, 1965)

27. Thuesen, H. F., and Fabrucky, W. G.
ENGINEERING ECONOMY.
3rd Ed. Prentice-Hall, Inc., Englewood Cliffs, N. J. (1964)

28. Gel'perin, N. I., Others.
ABSORPTION OF SULFUR DIOXIDE AND CARBON DISULFIDE IN HYDROCARBONS OF THE DIPHENYLMETHANE SERIES.
Zhur, Priklad. Khim. 31, 1323-32 (1958)
J. Applied Chem. USSR 31, 1309-17 (1958) - English Trans.

29. Balej, Jan, and Regner, Albert.
THE SYSTEM SULFUR DIOXIDE-DIMETHYLANILINE.
I. ABSORPTION ISOTHERMS.
Collection Czech. Chem. Communs. 21, 1545-52 (1956)
(in German)
II. HEATS OF SOLUTION.
Ibid. 1553-9
CA 51, 11831

30. Vian, A., Andres, A. Soler, and Fernandez, C. Iriarte.
STABILITY AND HEATS OF FORMATION IN PYRIDINES-SO_2 SYSTEMS OF INDUSTRIAL INTEREST.
Quim. Ind. (Bilbao) 13(2), 47-53(1966) (Span.)
CA 66 1991

31. Albright, Lyle F., Shannon, Paul T., Yu, Sun-Nien, and Chueh, Ping Lin.
SOLUBILITY OF SULFUR DIOXIDE IN POLAR ORGANIC SOLVENTS.
Chem. Eng. Progr., Symp. Ser. 59(44), 66-74 (1963)
CA 59, 3363

32. Smedslund, Tor H.
DIMETHYL SULFOXIDE AS SOLVENT FOR SULFUR DIOXIDE.
Finska Kemistsamfundets Medd. 59, 40-3 (1950)
CA 46, 4329

APPENDICES

APPENDIX A

Published solubilities of SO_2 in organic liquids are listed in Table A-1. Entries are in alphabetical order of compound names. Definition of symbols are found on page 9.

Where the original articles give tables of experimental results for solubility as a function of pressure, these data are usually listed with change of units to achieve uniformity. For a few compounds, only graphs are published, with the values tabulated below having been read from the graphs. Reference 28 reports measured solubilities for different temperatures at fixed pressures. These results have been plotted and the graphs used to find solubilities at 25 and 40° for different pressures.

The values of A for N, N-dimethylaniline are taken to be the reciprocals of the K values reported on page 1552 of Reference 29.

For N, N-dimethylacetamide and N, N-dimethylformamide, the total pressures given in Reference 30 have been corrected by subtracting the vapor pressures of the pure liquids.

TABLE A-1. Solubilities of SO_2 in Organic Liquids

Compound	t	w	r	P	x	P/x	A	Ref
Aniline	25	3. 77	17. 5	0. 0230	0. 052	0. 44(2)	0. 40(7)	7
		7. 57	37. 0	0. 0487	0. 099	0. 49(2)		
Diamylmethane (mixture of isomers)	25	0. 26	12. (9)	0. 017	0. 010(1)	1. 6(8)	1. 6(8)	28
		1. 09	53. 8	0. 0708	0. 041(3)	1. 71		
		3. 11	160	0. 21	0. 109(1)	1. 93		
		6. 80	439	0. 5775	0. 211(3)	2. 73		
	40	0. 64(3)	53. 8	0. 0708	0. 0247	2. 87	2. 7(6)	
		1. 93	160	0. 21	0. 070(6)	2. 97		
		4. 13	439	0. 5775	0. 139(9)	4. 12(8)		
N, N-Diethylaniline	25	8. 7(6)	119. 3	0. 1570	0. 169	0. 92(9)	0. 8(o)	8
		17. 6(0)	247. 5	0. 3257	0. 291	1. 11(9)		
		26. 4(8)	391. 6	0. 5153	0. 382	1. 34(9)		
		34. 4(6)	528. 0	0. 6947	0. 445	1. 56(1)		
		43. 3(5)	678. 0	0. 8921	0. 502	1. 77(7)		
2, 4-Dimethylpyridine	30	5. 8	4	0. 005	0. 088	0. 05(7)	0. 05	30
		11. 1	13	0. 017	0. 157	0. 10(9)		
		17. 7	25	0. 033	0. 228	0. 14(5)		
	40	5. 8	8	0. 011	0. 088	0. 12(5)		
		11. 1	26	0. 034	0. 157	0. 21(7)		
	50	5. 8	16	0. 021	0. 088	0. 24		
N, N-Dimethylacetamide	25	8. 6	14. (6)	0. 019(2)	0. 105	0. 18(3)	0. 11(0)	31
		14. 7	44. (6)	0. 058(7)	0. 166	0. 35(4)		
		31. 1	94. (2)	0. 123(9)	0. 297	0. 41(7)		
		47. 2	185. (3)	0. 263(4)	0. 391	0. 67(4)		
	38	8. 6	28. (3)	0. 037	0. 105	0. 35(4)	0. 23(6)	
		14. 7	68. (6)	0. 090	0. 166	0. 54(4)		
		31. 1	168. (4)	0. 222	0. 297	0. 74(6)		
		47. 2	310. (6)	0. 409	0. 391	1. 04(5)		

Compound	t	w	r	P	x	P/x	A	Ref
N, N-dimethylacetamide	66	8. 6	91. (5)	0. 120	0. 105	1. 15	0. 9(8)	
		14. 7	179. (4)	0. 236	0. 166	1. 42		
		30. 6	448. (8)	0. 591	0. 294	2. 01		
		46. 8	854. (7)	1. 125	0. 389	2. 89		
	93	8. 6	253	0. 333	0. 105	3. 17	2. 7(5)	
		14. 7	453	0. 596	0. 166	3. 59		
		30. 2	109. (2)	1. 43(7)	0. 291	4. 94		
		30. 5	111(7)	1. 47(0)	0. 293	5. 02		
		45. 6	191(4)	2. 51(8)	0. 383	6. 57		
N, N-Dimethylaniline	15	11. 83	5. 27				0. 02480	29
		20. 68	12. 30					
		22. 05	14. 19					
		24. 86	21. 51					
		32. 91	30. 30					
		40. 23	48. 70					
		45. 20	63. 4					
		47. 47	78. 6					
		48. 37	83. 6					
		50. 61	95. 0					
		54. 39	121. 0					
		60. 79	169. 5					
		65. 70	220. 5					
	20	16. 02	12. 25				0. 03895	
		16. 50	13. 25					
		22. 41	21. 23					
		26. 83	28. 08					
		30. 86	39. 90					
		31. 06	42. 20					
		43. 82	89. 0					
		50. 43	137. 3					
		51. 96	150. 0					
		60. 52	235. 5					

Compound	t	w	r	P	x	P/x	A	Ref
N, N-Dimethylaniline	25	11. 89	13. 10				0. 0617	
		12. 16	13. 78					
		19. 17	25. 72					
		27. 49	48. 0					
		27. 70	49. 7					
		29. 71	56. 0					
		37. 37	89. 2					
		41. 87	119. 5					
		47. 36	162. 0					
		54. 34	232. 5					
	40	3. 72	8. 98				0. 1862	
		4. 81	13. 30					
		8. 43	25. 80					
		11. 73	36. 30					
		12. 40	39. 10					
		13. 00	43. 00					
		17. 45	58. 5					
		22. 84	93. 5					
		24. 35	103. 95					
		30. 92	154. 9					
		31. 57	158. 0					
		38. 12	246. 0					
N, N-Dimethylformamide	25	19. 2	68. (4)	0. 090	0. 180	0. 50(0)	0. 43	31
		60. 1	23(4)	0. 30(8)	0. 407	0. 75(7)		
		146. (7)	99(4)	1. 30(8)	0. 626	2. 08(9)		
		348	199(2)	2. 62(1)	0. 799	3. 28(0)		
	38	19. 2	89. (2)	0. 177	0. 180	0. 65(0)	0. 48	
		60. 1	38(0)	0. 50(0)	0. 407	1. 22(9)		
		146. (1)	149(2)	1. 96(3)	0. 625	3. 14(1)		
		346	301(7)	3. 97(0)	0. 798	4. 97(5)		

Compound	t	w	r	P	x	P/x	A	Ref
N, N-Dimethylformamide	66	19. 2	212	0. 279	0. 180	1. 55	0. 80	
		59. 9	108(3)	1. 42(5)	0. 406	3. 51		
		143. (0)	328(1)	4. 31(8)	0. 620	6. 96		
		336	633(6)	8. 33(8)	0. 793	10. 5(1)		
	93	19. 2	493	0. 649	0. 180	3. 6(1)	1. 4(6)	
		58. 7	233(2)	3. 06(9)	0. 401	7. 6(5)		
		136. (5)	640(1)	8. 42(4)	0. 609	13. 8(3)		
		324	11840	15. 58	0. 787	19. 8(0)		
Dimethylsulfoxide	20	5. 2	5. 2	0. 0068	0. 059	0. 115	0. 104	32
		17. 1	21	0. 028	0. 173	0. 162		
		38. 1	71	0. 093	0. 317	0. 293		
Ditolylmethane	25	0. 32	12. (9)	0. 017	0. 009(7)	1. 7(5)	1. 7(0)	28
		1. 39	53. 8	0. 0708	0. 040(9)	1. 73		
		4. 19	160	0. 21	0. 113(8)	1. 85		
		9. 42	439	0. 5775	0. 224(0)	2. 58		
	40	0. 81	53. 8	0. 0708	0. 29(7)	2. 3(2)		
		2. 64	160	0. 21	0. 74(8)	2. 81		
		5. 58	439	0. 5775	0. 146(0)	3. 96		
N-Ethylaniline	25	9. 62	45. 0	0. 0592	0. 154	0. 384	0. 29	8
		19. 08	99. 5	0. 1309	0. 265	0. 494		
		28. 33	171. 0	0. 2250	0. 349	0. 645		
		37. 32	263. 0	0. 3461	0. 414	0. 836		
		49. 99	376. 5	0. 4954	0. 465	1. 065		
		54. 29	508. 5	0. 6691	0. 507	1. 320		
		62. 53	653. 5	0. 8599	0. 542	1. 587		
Ethyllaurate	25	23. 2	1090	1. 44	0. 453	3. 1(7)	2. 7	31
		49. 4	1860	2. 45	0. 638	3. 84		
		146	2580	3. 40	0. 839	4. 06		
		154	2630	3. 46	0. 846	4. 09		
1-Heptanol	25	33. 4	1530	2. 01	0. 377	5. 33	6. (4)	3
		92. 5	2260	2. 97	0. 626	4. 74		
		271	2610	3. 54	0. 831	4. 26		

Compound	t	w	r	P	x	P/x	A	Ref
1-Methylaniline	25	1.26	7.0	0.0092	0.0206	0.44(7)	0.4(4)	8
		2.93	15.5	0.0204	0.467	0.43(7)		
		4.42	28.5	0.0375	0.0688	0.545		
		6.22	40.5	0.0533	0.0942	0.566		
2-Methylaniline	15	9.0	23.0	0.0303	0.131	0.231	0.17(2)	8
		19.2	58.0	0.0763	0.243	0.314		
	25	8.6	40.5	0.0533	0.126	0.423	0.29(6)	
		19.4	121.5	0.1599	0.245	0.653		
		29.0	226.5	0.2980	0.327	0.911		
N-Methylaniline	25	7.4	17.5	0.0230	0.110	0.204	0.16(5)	8
		15.4	40.0	0.526	0.205	0.257		
		23.7	70.5	0.0928	0.284	0.326		
		31.4	112.4	0.1479	0.344	0.430		
		39.0	164.1	0.2159	0.395	0.547		
		46.2	235.0	0.3092	0.436	0.709		
		53.6	327.0	0.4303	0.473	0.910		
		60.4	434.0	0.5711	0.502	1.138		
		66.7	550.5	0.7243	0.527	1.374		
2-Methylpyridine	30	5.8	5	0.007	0.077	0.09	0.08	30
		11.1	13	0.017	0.139	0.12		
		17.7	23	0.030	0.204	0.15		
Nitrobenzene	25	28.8	990	1.30	0.371	3.5(1)	3.(2)	31
		64.4	1620	2.13	0.569	3.7(5)		
		260	2470	3.25	0.842	3.8(6)		
		262	2550	3.35	0.843	3.9(7)		
2-Octanone	25	33.6	850	1.12	0.402	2.7(9)	1.9(7)	31
		77.7	1520	2.01	0.609	3.3(0)		
		292	2590	3.40	0.854	3.9(9)		
Quinoline	25	7.2	14.3	0.0188	0.127	0.148	0.06(5)	8
		11.0	34.2	0.0450	0.182	0.247		

Compound	t	w	r	P	x	P/x	A	Ref
Tetraethylene glycol dimethyl ether	25	6.4	32	0.042	0.157	0.26(4)	0.18(3)	31
		9.8	65	0.085	0.253	0.336		
		16.3	119	0.157	0.361	0.433		
		27.0	212	0.279	0.484	0.576		
		58.8	626	0.823	0.671	1.22(7)		
	38	6.4	64	0.084	0.157	0.53(3)	0.37(5)	
		9.8	116	0.153	0.253	0.60(5)		
		16.1	212	0.279	0.359	0.77(7)		
		26.9	381	0.502	0.483	1.03(8)		
	66	6.4	184	0.242	0.157	1.54	1.4(2)	
		9.7	336	0.442	0.252	1.75(5)		
		16.1	623	0.819	0.358	2.28(9)		
		27.0	1140	1.50	0.484	3.09(3)		
	93	6.4	448	0.589	0.157	3.7(5)	3.5(0)	
		9.7	819	1.077	0.251	4.2(9)		
		15.9	1480	1.95	0.355	5.4(9)		
		26.2	2560	3.37	0.476	7.0(8)		

APPENDIX B

1. Albertson, Noel F., and Fernelius, W. Conard.
ADDITION COMPOUNDS OF SO_2.
J. Am. Chem. Soc. 65, 1687-90 (1943)
CA 37, 6577

2. Albright, Lyle F., Shannon, Paul T., Yu, Sun-Nien, and Chueh, Ping Lin.
SOLUBILITY OF SULFUR DIOXIDE IN POLAR ORGANIC SOLVENTS.
Chem. Eng. Progr., Symp. Ser. 59(44), 66-74 (1963)
CA 59, 3363

3. Allison, S. A., and Barrer, R. M.
CLATHRATION BY PHENOL AND QUINOL. PART I. EQUILIBRIA.
Trans. Faraday Soc. 64(2), 557-65 (1968)

4. Anon.
HIGH-PURITY LIQUID SULFUR DIOXIDE FROM ROASTER GASES.
Chem. Eng. 60, No. 4, 274-7 (1953)
CA 47, 4659

5. Anon.
RECOVERY OF SULFUR FROM SPENT OXIDE.
Gas World 57, 497
CA 7, 547

6. Anon.
THE SULFIDINE PROCESS FOR RECOVERING SULFUR DIOXIDE.
Ind. Eng. Chem., News Ed. 14, 105 (March 1936)
CA 36, 6497

7. Asinger, Friedrich, Schmidt, Walter, and Ebeneder, Franz.
PRODUCTS OF THE SIMULTANEOUS ACTION OF SULFUR DIOXIDE AND CHLORINE ON ALIPHATIC HYDROCARBONS IN ULTRAVIOLET LIGHT. I. PRODUCTS OF THE SIMULTANEOUS ACTION OF SULFUR DIOXIDE AND CHLORINE ON PROPANE IN CARBON TETRACHLORIDE SOLUTION.
Ber. 75B, 34-41 (1942)
CA 39, 3251

8. Asinger, Friedrich.
PRODUCTS OF THE COMBINED ACTION OF SO_2 AND Cl ON ALIPHATIC HYDROCARBONS IN ULTRAVIOLET LIGHT.
IV. PRODUCTS OF THE COMBINED ACTION OF SO_2 AND Cl ON DODECANE.
Ber. 77B, 191-4 (1944)
CA 37, 3048

9. Avdeeva, A. J., and Pitelina, N. P.
SOLUBILITY OF SULFUR-CONTAINING GASES IN OILS.
Khim. Prom. 1947, No. 2, 19-21
CA 41, 5775

10. Backer, H. J., and Strating, J.
CYCLIC SULFONES DERIVED FROM BUTADIENES.
Rec. Trav. Chim. 53, 525-43 (1934)
CA 28, 1697

11. Backer, H. J., Strating, J., and Huisman, L. H. H.
ADDITION OF SULFUR DIOXIDE TO 1,1′ BICYCLOHEXENYL. FORMATION OF DERIVATIVES OF DIBENZOTHIOPHENE SULFONE.
Rec. Trav. Chim. 60, 381-90 (1941)
CA 36, 89

12. Balej, Jan, and Regner, Albert.
THE SYSTEM SULFUR DIOXIDE-DIMETHYLANILINE.
I. ABSORPTION ISOTHERMS.
Collection Czech. Chem. Communs. 21, 1545-52 (1956) (in German)
II. HEATS OF SOLUTION.
Ibid. 1553-9
CA 51, 11831

13. Barwasser, J., and Roesner, G.
OBTAINING SULFUR DIOXIDE FROM INDUSTRIAL GASES.
Reichsant Wirtschaftsausbau, Chem. Ber. Pruf.-Nr. 93 (PB 52008), 135-48 (1940) (Pub. 1941)
CA 41, 6374 (1947)

14. Baume, G., and Pamfil, G.
FUSIBILITY CURVES OF GASEOUS MIXTURES, COMPOUNDS OF HYDROGEN CHLORIDE AND SULFUR DIOXIDE WITH METHYL ALCOHOL.
Compt. Rend., 152, 1095-7
CA 5, 2769

15. Baume, G.
VOLATILE SYSTEMS. FUSIBILITY CURVES OF THE SYSTEMS FORMED BY METHYL OXIDE WITH HYDROCHLORIC ACID, WITH SULFUR DIOXIDE AND WITH METHYL CHLORIDE.
J. Chim. Phys. 12, 216-24 (1914); 9, 245 (1911)
Compt. Rend. 148, 1322 (1909)
CA 9, 547

16. Baume, G., and Pamfil, G. P.
VOLATILE SYSTEMS. FUSIBILITY CURVES OF SYSTEMS FORMED BY HYDROCHLORIC ACID AND SULFUR DIOXIDE WITH METHYL ALCOHOL. MECHANISM OF ESTER FORMATION.
J. Chim. Phys. 12, 256-69 (1914)
CA 9, 547

17. Bhatnagar, Vijay Mohan (Punjab Univ., Chandigarh, India).
CLATHRATE COMPOUNDS OF QUINOL.
Def. Sci. J. (N. Delhi), Suppl. 13(4), 57-66 (1963) Eng.)
CA 67, 121180

18. Bianconi, A., and Bianchi, A.
THE CHEMICAL REACTION BETWEEN SULFUROUS ACID AND COMPOUNDS OF AN ALDEHYDIC OR KETONIC NATURE.
Ann. Chim. Applicata 22, 291-316 (1932)
CA 26, 6025

19. Bienstock, D., Others.
SULFUR DIOXIDE - ITS CHEMISTRY AND REMOVAL FROM INDUSTRIAL WASTE GASES
U. S. Bureau of Mines Info. Circular 7836 (1958)
TN 1. U56 #7836

20. Binns, Frederick W., and Lurie, Joseph M.
SULFUR DIOXIDE ADDITION DERIVATIVE OF NITROSO-β-NAPHTOL.
U. S. 1,822,122, Sept. 8
CA 25, 5901

21. Blohm, C. L.
PROCESSING SULFUR BEARING GASES.
Petroleum Eng. 24, C68-74 (April 1952)
Eng. Index 1952

22. Boeseken, J., and Muller, H. D.
PRECISE DETERMINATION OF VERY SMALL QUANTITIES OF GASES CONTAINING SULFUR (HYDROGEN SULFIDE, SULFUR DIOXIDE AND CARBON DISULFIDE) IN THE ATMOSPHERE WHEN THEY ARE PRESENT SIMULTANEOUSLY.
Rec. Trav. Chim. 50, 1117-24 (1931)
CA 26, 1212

23. Brehmer, T. E., and Nirkko, P.
SULFUR DIOXIDE AND DIMETHYLANILINE.
Finska Kemistsamfundets Medd. 65, 19-24 (1956) (in Swedish)
CA 50, 13566

24. Brehmer, T. E., and Ruuskanen, P. (Tek. Hogskolan, Helsingfors)
THERMODYNAMIC PROPERTIES OF SOME SOLVENTS USED IN ABSORPTION-TECHNIQUE REFRIGERATION.
Finska Kemistsamfundets Medd. 60, 20-34 (1951)
CA 46, 10838

25. Bright, J. Russell, and Jasper, Joseph J.
MOLECULAR SURFACE ENERGY OF SULFUR DIOXIDE ADDITION COMPOUNDS. I.
J. Am. Chem. Soc. 63, 3486-8 (1941)
CA 36, 947

26. Bright, J. Russell, and Jasper, Joseph J.
MOLECULAR SURFACE ENERGY OF SULFUR DIOXIDE ADDITION COMPOUNDS. II.
J. Am. Chem. Soc. 65, 1262-3 (1943); cf. CA 36, 947
CA 37, 4944

27. Bright, J. Russell, and Fernelius, W. Conard.
TEMPERATURE-CONCENTRATION EQUILIBRIA IN THE SYSTEM DIMETHYLANILINE-SULFUR DIOXIDE.
J. Am. Chem. Soc. 65, 637-9 (1943)
CA37, 3326

28. Briner, E., and Cardoso, E.
THE COMPRESSIBILITY AND VAPOR PRESSURE OF MIXTURES OF METHYL OXIDE AND SULPHUR DIOXIDE.
Compt. Rend., 144 911-13 (1907)
CA1, 1818

29. Burg, A. B.
THE BEHAVIOR OF Me_3N, Me_3NSO_3, and Me_3NO TOWARD SO_2.
J. Am. Chem. Soc. 65, 1629-35 (1943)
CA 37, 5641

30. de Carli, F.
ADDITION PRODUCTS OF SULFUR DIOXIDE AND AROMATIC HYDROCARBONS.
Alli Accad. Lincei (6) 4, 460-6 (1926)
CA 21, 738

31. de Carli, F.
ADDITION PRODUCTS OF SULFUR DIOXIDE AND AROMATIC HYDROCARBONS. II.
Alli Accad. Lincei (6) 4, 523-30 (1926)
CA 21, 1449

32. Christian, Sherril D., and Grundnes, Just. (Univ. Oslo, Norway).
CHARGE-TRANSFER COMPLEX BETWEEN SULFUR DIOXIDE AND TRIMETHYLAMINE IN THE GAS PHASE AND IN HEPTANE.
Nature 214 (5093), 1111-12 (1967)(Eng.); cf. Burg, CA 37, 5641
CA 67, 69057

33. Collin, F. C.
PURIFICATION OF GASES FROM METALLURGICAL PLANTS AND RECUPERATION OF SULFUR DIOXIDE.
Tids. Kjemi, Bergvesen Met. 1, 112-17 (1941)
CA 36, 5738

34. Cupr, Vaclav.
THE ABSORPTION OF HYDROGEN CHLORIDE AND SULFUR DIOXIDE IN SULFURIC ACID AND ACETIC ACID.
Spisy Vydavane Prirodovedeckou Fakulton Masarykovy Univ. 1926, No. 68, 5-17
CA 20, 3781

35. Cupr, Vaclav.
THE ABSORPTION OF HYDROCHLORIC ACID GAS AND SULFUR DIOXIDE IN SULFURIC AND ACETIC ACIDS.
Rec. Trav. Chim. 47, 55-72 (1928)
CA 22, 1262

36. Dodgson, John W.
REDUCTION OF SUBSTITUTED p-BENZOQUINONES BY SULFUR DIOXIDE ALONE AND IN THE PRESENCE OF ALKALI.
J. Chem. Soc. 1930, 2498-2502; cf. CA 9, 206
CA 25, 691

37. Dokladalova, J., and Stankova, O., (Univ. Olomouc, Czech.).
THE SCHIFF REACTIONS WITH THE USE OF COMPLEXED SULFUR DIOXIDE.
Mikrochim. Acla 1968 (1), 219-27(Ger.)
CA 68, 56442

38. Dunken, H., and Winde, H.
INTERACTIONS OF SULFUR DIOXIDE WITH POLAR COMPOUNDS. EFFECTS OBSERVED IN THE UV ABSORPTION SPECTRUM.
Z. Phys. Chem. (Frankfurt am Main) 56(5-6), 303-8 (1967)(Ger.)
CA-68, 86647

39. Ebel, C.
DIE FABRIKATION VON SCHUHCREME UND BOHNERWACHS. BAND 45 OF "MONOGRAPHIEN UBER CHEMISCH-TECHNISCHE FABRIKATIONSMETHODEN."
Berlin, Hirschwalksche Buchhandlung. 168 pp.
CA 24, 3864

40. Emelin, V. P., Zolotarev, E. K., and Yudin, A. M.
KINETICS OF ABSORPTION OF SULFUR TRIOXIDE IN THE SULFONATION OF NITROBENZENE BY GASEOUS SO_3.
Khim. Prom. 1965(1), 30-1 (Russ.)
CA 62, 8961

41. Ephraim, Fritz, and Piotrowski, H.
ACTION OF SULFUR AND COMPOUNDS CONTAINING SULFUR ON HYDRAZINE.
Ber. 44, 386-94
CA 5, 1880

42. Feigl, F, and Feigl, E.
THE TERNARY COMPOUNDS OF SULFUR DIOXIDE WITH KETONES AND AMINES.
Z. Anorg. Allgem. Chem.
CA 26, 1576

43. Fernelius, W. Conard, Audrieth, Ludwig F, Bailar, John C., Jr. Booth, Harold S., Johnson, Warren C., Kirk, Raymond C., Schumb, Walter C., and Scott, Janet D.
INORGANIC SYNTHESIS.
Inorg. Syntheses II, 294 pp. (1946) - 48
CA 40, 7025

44. Ferroni, Enzo, and Cocchi, Marco. (Univ. Florence)
EPITAXY OF CLATHRATES.
Ann. Chim. (Rome) 48, 530-6 (1958); cf. CA 52, 14301d
CA 53, 16633

45. Fleming, E. P., and Fitt, T. C.
LIQUID SULFUR DIOXIDE FROM WASTE SMELTER GASES. USE OF DIMETHYLANILINE AS ABSORBENT.
Ind. Eng. Chem. 42, 2253-58 (1950)

46. Fluck, Ekkehard, and Binder, Herbert. (Univ. Heidelberg, Ger.
NUCLEAR MAGNETIC RESONANCE OF PHOSPHORUS COMPOUNDS. XVI. REACTIONS OF PHOSPHORUS(III) COMPOUNDS WITH SULFUR DIOXIDE.
Z. Anorg. Allg. Chem. 354(3-4), 139-48 (1967)(Ger.)
CA68, 25326

47. Foote. H. W., and Fleischer, Joseph.
EQUILIBRIUM IN SYSTEMS COMPOSED OF SULFUR DIOXIDE AND CERTAIN ORGANIC COMPOUNDS.
J. Am. Chem. Soc. 56, 870-3 (1934); cf. CA 25, 3551; 26, 5822
CA 28, 3290

48. Frederick, D. S., Cogan, H. D., and Marvel, C. S.
REACTION BETWEEN SULFUR DIOXIDE AND OLEFINS. CYCLOHEXENE.
J. Am. Chem. Soc. 56, 1815-19 (1934)
CA 28, 6118

49. Gel'perin, N. I., Others.
ABSORPTION OF SULFUR DIOXIDE AND CARBON DISULFIDE IN HYDROCARBONS OF THE DIPHENYLMETHANE SERIES.
Zhur. Priklad. Khim. 31, 1323-32 (1958)
J. Applied Chem. USSR 31, 1309-17 (1958) - English Trans.

50. Gerhards, Erich, and Dirscherl, Wilhelm. (Univ. Bonn, Ger.).
REACTION OF SO_3 WITH CYCLOHEXANE; PREPARATION OF A POLYENEDIHYDROXYDISULFONIC ACID.
Ann. 642, 71-82 (1961)
CA 55, 71094

51. Gilbert, E. E.
REACTIONS OF SULFUR TRIOXIDE AND OF ITS ADDUCTS WITH ORGANIC COMPOUNDS.
Chem. Res. 62, 549-89 (1962)

52. Gilford, Martin, and Gordon, Saul.
THERMOANALYTICAL CHARACTERIZATION OF SEVERAL QUINOL CLATHRATE COMPOUNDS.
U. S. Dept. Com., Office Tech. Serv., P B Rept. 145, 517, 23 pp. (1960)
CA 57, 380

53. Goliath, Marit, and Lindgren, Bengt O. (Forest Prods. Res. Lab., Stockholm)
MECHANISM OF REDUCTION OF SULFUR DIOXIDE BY FORMIC ACID.
Acla. Chem. Scand. 16, 570-4 (1962)(in English)
CA 51, 5558

54. Gomes, A., and Joullie, M. M.
CYCLOADDITION OF KETENE AND IMINES TO SULFUR DIOXIDE.
Chem. Commun. 1967(18), 935-6(Eng.)
CA 68, 21875

55. Good, A., and Thynne, J. C. J. (Univ. Edinburgh, Scot.)
REACTION OF FREE RADICALS WITH SULFUR DIOXIDE. I. METHYL RADICALS.
Trans. Faraday Soc. 63(11), 2708-19 (1967)(Eng.)
CA 68, 12219 and 12220

56. Guiselin, A. L. C.
USE OF MINERAL OILS AS SOLVENTS FOR SULFUR DIOXIDE.
Mat. Grasses, 6, 3144-5
CA 7, 4048

57. Guss, L. S., and Kolthoff, I. M.
THE BEHAVIOR OF SO_2 AS AN ACID IN MeOH.
J. Am. Chem. Soc. 66, 1484-8 (1944)
CA 38, 6165

58. Guyot, J., and Simon, L. J.
ACTION OF SULFURIC ANHYDRIDE AND OLEUM ON METHYL ALCOHOL. PREPARATION OF DIMETHYL SULFATE.
Compt. Rend. 169, 795-7 (1919); cf. CA 14, 403
CA 14, 539

59. Hamill, Wm. H.
EQUILIBRIA IN SOLUTIONS.
Proc. Indiana Acad. Sci. 51, 165-6 (1941)(Pub. 1942)
CA 37, 22

60. Hampson, N. H.
ECONOMIC ELIMINATION OF AIR POLLUTION THROUGH RECOVERY OF PRODUCTS IN POLYESTER GAS SCRUBBERS.
Allg. Papier-Rundschau No. 21, 1392, 1394, 1396 (1965)
CA 66, 31834

61. Hexter, R. M., and Goldfarb, T. D.
INFRARED SPECTRA OF QUINOL CLATHRATE COMPOUNDS.
J. Inorg. & Nuclear Chem. 4, 171-8 (1957)
CA 51, 12660

62. Hill, Arthur E.
REACTION OF AMINES WITH SULFUR DIOXIDE.
I. ANILINE AND SULFUR DIOXIDE.
J. Am. Chem. Soc. 53, 2598-2608 (1931)
CA 25, 4482

63. Hill, Arthur E., and Fitzgerald, Thomas B.
COMPOUNDS OF SULFUR DIOXIDE WITH VARIOUS AMINES.
J. Am. Chem. Soc. 57, 250-4 (1935)
CA 29, 1689

64. Hird, S. A., and Lloyd, L. L.
THE ACTION OF SULFUR DIOXIDE UPON OILS
J. Soc. Chem. Ind., 31, 316-9
CA 6, 1688

65. Hoffman, Kenneth R., and VanderWerf, Calvin A.
ADDITION COMPOUNDS OF SULFUR DIOXIDE WITH PYRIDINE AND THE PICOLINES.
J. Am. Chem. Soc. 68, 997-1000 (1946)
CA 40, 5433

66. Horiuchi, Juro.
THE SOLUBILITY OF GAS AND THE COEFFICIENT OF DILATATION BY ABSORPTION. II.
Bull. Inst. Phys. Chem. Research (Tokyo) 9, 697-730 (1930)
CA 25, 3543

67. Horiuchi, Juro.
THE SOLUBILITY OF GAS AND THE COEFFICIENT OF DILATATION BY ABSORPTION. III.
Bull. Inst. Phys. Chem. Res. (Tokyo) 10, 374-401
CA 25, 5609

68. Hunt, Madison, and Marvel, C. S.
REACTION BETWEEN SULFUR DIOXIDE AND OLEFINS. II. PROPYLENE.
J. Am. Chem. Soc. 57, 1691-6 (1935); cf. CA 28, 6118
CA 29, 7276

69. Ingles, D. L. (C. S. I. R. O., Div. Food Preservation, North Ryde, Australia)
SOME NOVEL ADDUCTS OF SULFUR DIOXIDE WITH CARBONYLS AND AMINO ACIDS.
Chem. Ind. (London) 1967(35) 1492-3(Eng.)
CA 68, 96115

70. Ipatieff, V. N., and Monroe, G. S.
DETERMINATION OF SOLUBILITIES OF GASES AT HIGH TEMPERATURES AND HIGH PRESSURES BY THE ROTATING BOMB.
Ind. Eng. Chem. Anal. Ed. 14, 166-71 (1942)
CA 36, 2196

71. Ishikawa, Fusao, Mitsui, Saburo, and Murooka, Toyosaku.
EQUILIBRIUM IN THE SYSTEM CONSISTING OF CAMPHOR AND SULFUR DIOXIDE.
Sci. Repts. Tohoku Imp. Univ., 1st Ser. 23, 852-70 (1935)
Bull. Inst. Phys. Chem. Res. (Tokyo) 13, 684-96 (1934)
CA 29, 4245

72. Ivanov, Trifon. (Inst. Technol Super. Ind. Alimentaires, Plovdiv, Bulg.).
OXIDATION OF GRAPE MUST. II. A COMPARATIVE STUDY OF SULFUR DIOXIDE AND BENTONITE RN AS INACTIVATORS OF GRAPE MUST POLYPHENOLOXIDASE.
Ann. Technol. Agr. 16(2), 81-8 (1967)(Fr.); cf. CA 67, 72433g
CA 68, 28446

73. Jasper, Joseph J., and Bright, J. Russell.
MOLECULAR SURFACE ENERGY OF SO_2 ADDITION COMPOUNDS. III.
J. Am. Chem. Soc. 66, 105-6 (1944); cf. CA 37, 4944
CA 38, 1157

74. Jeffrey, G. A., and McMullan, R. K.
THE CLATHRATE HYDRATES
Prog. in Inorg. Chem. 8, 43-108 (1967)
CA 68, 56004

75. Johnstone, H. F.
RECOVERY OF SULFUR DIOXIDE FROM WASTE GASES. EQUILIBRIUM PARTIAL VAPOR PRESSURES OVER SOLUTIONS OF THE AMMONIA-SULFUR DIOXIDE-WATER SYSTEM.
Ind. Eng. Chem. 27, 587-93 (1935)
CA 29, 4137

76. Johnstone, H. F., Read, H. J., and Blankmeyer, H. C.
RECOVERY OF SULFUR DIOXIDE FROM WASTE GASES. EQUILIBRIUM VAPOR PRESSURES OVER SULFITE-BISULFITE SOLUTIONS.
Ind. Eng. Chem. 30, 101-9 (1938)
CA 32, 1874

77. Kalaushin, A. E., Leont'eva, L. S., Frumkina, A. Kh, and Kas'yan, D. T.
PROCESS OF RENDERING HARMLESS SULFUR WASTE GASES UNDER FOAM CONDITIONS.
Neftepererab. Neftekhim. 1967(9), 30-2(Russ.)
CA 68, 51692

78. Kangun, I.
THE DETERMINATION OF SULFUR DIOXIDE IN THE PRESENCE OF OXIDES OF NITROGEN IN THE CHAMBER AND TOWER GASES.
J. Chem. Ind. (Moscow) 1934, No. 5, 33-5
CA 28, 5365

79. Katz, M., and Cole, R. J.
RECOVERY OF SULFUR COMPOUNDS FROM ATMOSPHERIC CONTAMINANTS.
Ind. Eng. Chem. 42, 2258-69 (Nov. 1950)

80. Kerp, W., and Wohler, P.
CONTRIBUTION TO THE KNOWLEDGE OF COMBINED SULPHUROUS ACID.
Arb. Kais. Gesundheitsamt., 32, 120-43
CA 4, 380

81. Konopator, A. P., and Strom, L. D.
PRODUCTION OF SULFUR FROM HYDROGEN SULFIDE OF REFINERY GASES.
Neftepererab. Neftekhim. 1967(2), 25-9 (Russian)
CA 67, 13550

82. Kulcsar, Geza J., Makkay-Beke, Clara, and Vodnar, Ioan.
THE SYSTEM SO_2-ANILINE. I. ABSORPTION ISOTHERMS.
Studia Univ. Babes-Bolyai 1, No. 2, 163-71 (1960)
CA 56, 5795

83. Kulcsar, Geza J., Vodnar, Ioan, and Santa, Stefan.
THE SYSTEM SO_2-ANILINE.
II. DETERMINATION OF THE HEAT OF ABSORPTION
Studia Univ. Babes-Bolyai Ser. I, No. 2, 155-8 (1961)
cf. CA 56, 5795b
CA 57, 10578

84. Kulcsar, Geza J., and Lengyel-Szabo, Gyorgyi. (Univ. Babes-Bolyai, Cluj, Romania)
THE SYSTEM SULFUR DIOXIDE-ANILINE.
III. ABSORPTION ISOTHERMS IN AQUEOUS SOLUTION.
Studia Univ. Babes-Bolyai, Ser. Chemia 9(1), 77-83 (1964)
cf. CA 57, 10578c
CA 61, 15403

85. Lecher, Z., and Hardy, W. B.
COMPOUNDS OF TRIALKYLAMINE OXIDES WITH SULFUR DIOXIDE AND TRIOXIDE. II.
J. Am. Chem. Soc. 70, 3789-92 (1948)
CA 43, 2574

86. Lepouse, Hector.
THE ACTION OF SULFURIC ACID AND SULFURIC ANHYDRIDE ON ACETYLENE DICHLORIDE.
Bull. Soc. Chim. Belg. 34, 133-42 (1925)
CA 19, 2323

87. Lloyd, Stewart J.
SOME SOLUBILITY MEASUREMENTS.
J. Phys. Chem. 22, 300-3 (1918)
CA 12, 1433

88. Locket, Geo. H.
MOLECULAR ASSOCIATION OF AROMATIC HYDROCARBONS WITH THIONYL CHLORIDE, SULFURYL CHLORIDE AND SULFUR DIOXIDE.
J. Chem. Soc. 1932, 1501-12
CA 26, 403

89. MacFarlane, Walter, and Wright, Robert.
SOLUBILITY OF VAPORS IN GASES.
J. Chem. Soc. 1934, 207-10
CA 28, 3952

90. Makrauczy, Jozsef, and Mohai, Bela.
GAS ABSORPTION STUDIES. XI. ACID-BASE EQUILIBRIUMS.
1. ABSORPTION OF SULFUR DIOXIDE IN POTASSIUM, AMMONIUM, AND BARIUM HYDROXIDE SOLUTIONS.
Veszpremi Vegyip. Egyet. Kozlemeny. 6, 173-82 (1962); cf. CA 57, 4505b
CA 58, 6252

91. Marks, G. W., and Ambrose, P. M.
DIETHYLENETRIAMINE AND OTHER AMINES AS AGENTS FOR THE RECOVERY OF SULFUR DIOXIDE.
U. S. Bur. Mines, Rept. Investigations No. 3339, 41-6 (1937)
CA 31, 6422

92. Mazzetti, C., and de Carli, F.
ADDITION PRODUCTS OF SULFUR DIOXIDE WITH BENZENE.
Gazz. Chim. Ital. 56, 34-6 (1926)
CA 20, 1984

93. Michael, Arthur, and Weiner, Nathan.
MECHANISM OF THE SULFONATION PROCESS.
J. Am. Chem. Soc. 58, 294-8 (1936)
CA 30, 2922

94. Mousseron, Max.
ALICYCLIC S DERIVATIVES.
Compt. Rend. 216, 812-14 (1943); cf. CA 38, 3623
CA 38, 4568

95. Mousseron, Max., and Granger, Robert.
VI. THE ORGANOMAGNESIUM COMPOUNDS.
Bull. Soc. Chim. 1946, pp. 251-56
CA 40, 6430

96. Naulmann, A.
REACTIONS IN NON-AQUEOUS SOLUTIONS.
VI. IN ACETONITRILE.
Giessen. Ber., 4[illegible], 247-56; cf. CA 4, 1851
CA 8, 1373

97. Nelson, H. W., and Lyons, C. J.
SOURCES AND CONTROL OF SULFUR-BEARING POLLUTANTS.
J. Air Pollution Control Assoc. 7(3), 187-93 (Nov. 1957)

98. Overberger, C. G., and Moore, J. A.
COPOLYMERIZATION OF BENZYL VINYL SULFIDE WITH SULFUR DIOXIDE.
Chem. Ind. (London) 1968(1), 24 (Eng.)
CA 68, 50095

99. Palin, D. E., and Powell, H. M.
THE STRUCTURE OF MOLECULAR COMPOUNDS.
PART III. STRUCTURE OF ADDITION COMPLEXES OF QUINOL WITH CERTAIN VOLATILE COMPOUNDS.
J. Chem. Soc. 1947, 208-21 (1947)
Progress in Inorganic Chem. Vol. 8 p. 103

100. Pasteur, Felix
SOME PROPERTIES OF FENCHONE.
Bull. Sci. Pharmacol. 38, 279-81 (1931)
CA 25, 4164

101. Paul, Ram Chand, Ahluwalia, S. C., and Pahil, Sarvinder Singh.
(Univ. Panjab, Chandigarh).
THERMOCHEMICAL STUDIES IN DIMETHYLFORMAMIDE.
I. HEATS OF SOLUTION AND NEUTRALIZATION OF LEWIS ACIDS.
Indian J. Chem. 3(7), 300-4 (1965)(Eng.)

102. Paul, Ram Chand, Narula, Saraj Parkash, and Mayer, Prabha.
(Panjab Univ., Chandigarh).
CONDUCTOMETRIC STUDIES OF MIXTURES OF SULFUR TRIOXIDE WITH ORGANIC ESTERS.
Bull. Nat. Inst. Sci. India No. 29, 209-13 (1965)(Eng.)
CA 67, 119429

103. Paul, Ram Chand, and Bains, M. S.
(Panjab Univ., Chandigarh, India).
COORDINATION CHEMISTRY OF SULFUR TRIOXIDE WITH OXYGEN BASES.
Proc. Int. Conf. Coord. Chem., 8th, Vienna 1964, 366-9 (Eng.); cf. CA 63, 10986c, 15118c
CA 67, 81740

104. Pfeifer, Gyula. (Nehezvegyipari Kutato Int., Veszprem, Hung.)
ABSORPTION OF SO_2 IN DIMETHYIFORMAMIDE (DMF).
Magy. Kem. Folyoiral 69, No. 3, 138-41 (1963)
CA 59, 33638

105. Pipik, O. G.
A NEW METHOD FOR DETERMINING THE REACTIVITY OF ORGANIC SUBSTANCES.
Azerbaidzhanskoe Neftyanoe Khozyaislvo 1936, No. 12, 60-8
CA 32, 4515

106. Pond, Wm. F.
DETERMINATION OF THE QUANTITY OF SULFUR DIOXIDE ABSORBED BY A LIQUID.
Chemist-Analyst 18, No. 4, 10-11 (1929)
CA 23, 5357

107. Postnikov, V. F., and Astasheva, A. A.
THE ABSORPTION OF SULFUR DIOXIDE BY XYLIDINE.
J. Chem. Ind. USSR 17(3), 14-19 (1940)
CA 34, 6777

108. Postnikov, V. F., and Kunin, T. I.
EXTRACTION OF SULFUR DIOXIDE FROM THE WASTE GASES OF CONTACT SULFURIC ACID PLANTS.
Trans. Inst. Chem. Tech. Ivanovo (USSR) No. 2, 56-70 (1939)
CA 33, 8927

109. Powell, H. M.
THE STRUCTURE OF MOLECULAR COMPOUNDS. PART IV. CLATHRATE COMPOUNDS.
J. Chem. Soc. 1948, 61-73 (1948)

110. Pupezin, Jovan; Ribnikar, Slobodan; Knezevic, Zivojin; and Dokic, Vidosava.
LIQUID-VAPOR EQUILIBRIUM AND THERMODYNAMIC PROPERTIES OF THE SYSTEM SULFUR DIOXIDE + DIMETHYL ETHER.
Bull. Boris Kidric Inst. Nucl. Sci. 17(4), 297-309 (1966)(Eng.)
CA 67, 47783

111. Ragimov, F. M., Kalaushin, A. E., Leont'eva, L. S., Frumkina, A. Kh., and Kas'yan, D. T.
REMOVING SULFUR DIOXIDE IN FOAM MIXING CHAMBERS.
Azerb. Neft. Khoz. 44 (8), 38-40 (1965) (Russ.)
CA 64, 4835

112. Reid, W. S.
CONCENTRATION OF THE SULFUR DIOXIDE CONTENT OF DWIGHT-LLOYD SINTERING-MACHINE GAS BY RECIRCULATION.
J. Metals 1(4), Trans. 261-6 (1949)
CA 43, 3753

113. Renzanigo, F.
ANALYTICAL DETERMINATION OF SMOKE POLLUTANTS FROM COMBUSTION IN DOMESTIC HEATING UNITS.
Riv. Combust. 21(10), 506-20 (1967)(Ital).
CA 68, 81176

114. Ries, E. D., and Clark, I. E.
ANALYSIS OF SULFUR DIOXIDE IN THE PRESENCE OF EXCESS AIR.
Ind. Eng. Chem. 18, 747 (1926)
CA 20, 2800

115. Riezebos, Gerrit; van Dorp, David A., and Schweigl, Othmar F.
N-SUBSTITUTED AMINOALKANESULFONIC ACIDS FOR DETERGENTS.
U. S. 3, 346, 628 (Cl. 260-501), Oct. 10, 1967
CA 67, 116576

116. Ringstorff, G. W.
ROLE OF METHANE AND OTHER FACTORS IN CONTROLLING EMISSIONS FROM STEELMAKING PROCESSES.
Met. Soc. AIME-Open Hearth Proc. 46, 438-56 (1963)
Eng. Index 1966, p. 61

117. Roberson, A. H., and Marks, G. W.
FIXATION OF SULFUR FROM SMELTER SMOKE. PARTIAL PRESSURES OF SULFUR DIOXIDE OVER SOLUTIONS OF SULFUR DIOXIDE IN MIXTURES OF WATER AND VARIOUS ALIPHATIC AMINES.
U. S. Bur. Mines, Rept. Investigations 3415, 45 pp. (1938)
CA 33, 9499

118. Roesner, G.
THE SULFIDIN METHOD, A NEW METHOD OF UTILIZATION OF GASES CONTAINING SULFUR DIOXIDE.
Metallu. Erz 34, 5-11 (1937)
CA 31, 1964

119. Rotariu, George J., Hoskins, Elizabeth L., and Hattori, Donald M.
DEVELOPMENT OF KRYPTON-85 CLATHRATE ANALYTICAL TECHNIQUES TO MEASURE OXIDATION-REDUCTION PRODUCTS IN THE LIQUID STATE.
U. S. At. Energy Comm. TI D-17223, 98 pp. (1962)
CA 60, 1106

120. Rothenfusser, S.
DETECTION AND DETERMINATION OF SULFUR DIOXIDE.
Z. Untersuch, Lebensm, 58, 98-109 (1929)
CA 24, 1056

121. Ryden, L. L., and Marvel, C. S.
REACTION BETWEEN SULFUR DIOXIDE AND OLEFINS. III. HIGHER OLEFINS AND SOME LIMITATIONS OF THE REACTION.
J. Am. Chem. Soc. 57, 2311-14 (1935); cf. CA 29, 7276
CA 30, 75

122. Ryden, L. L., and Marvel, C. S.
POLYSULFONES FROM ACETYLENES AND SULFUR DIOXIDE.
J. Am. Chem. Soc. 58, 2047-50 (1936); cf. CA 30, 75
CA 30, 8184

123. Ryss, I. G., and Bogdanova, L. P.
SYNTHESIS AND HYDROLYSIS KINETICS OF β-PICOLINE SULFUR TRIOXIDE COMPLEX.
Zh. Neorg. Khim. 12(8), 2091-3 (1967) (Russ.)
CA 68, 12092

124. Schaafsma, A.
THE DISTRIBUTION OF SULFUR DIOXIDE BETWEEN WATER AND GASOLINE.
Chem. Weekblad 35, 821-3 (1938)
CA 33, 2007

125. Schmidt-Nickels, Wilhelm.
THE ACTION OF SULFUR DIOXIDE ON THE BALOMAGNESYL DERIVATIVES OF THE CARBINOLS.
Ber. 62B, 917-9 (1929)
CA 23, 5180

126. Schumacher, H. J., and Stauff, J.
REACTIONS OF HYDROCARBONS WITH SULFURYL CHLORIDE AND SULFUR DIOXIDE-CHLORINE MIXTURES.
Die Chemie 53, 341-5 (1942)
CA 37, 5366

127. Seyer, W. F., and Cornett, W. F.
THE SYSTEM SULFUR DIOXIDE-DECALIN.
Ind. Eng. Chem. 29, 91-2 (1937)
CA 31, 3367

128. Seyer, W. F., and Gallaugher, A. F.
THE SYSTEM SULFUR DIOXIDE AND NORMAL OCTANE.
Trans. Roy. Soc. Can. 20, 343-5 (1926); cf. CA 20, 2607
CA 21, 2572

129. Seyer, W. F., and Todd, E.
CRITICAL SOLUTION TEMPERATURES OF SYSTEMS OF SULFUR DIOXIDE AND NORMAL PARAFFINS.
Ind. Eng. Chem. 23, 325-7 (1931)
CA 25, 2040

130. Seyer, W. F., Martin, K., and Hodnett, L.
SYSTEMS OF SULFUR DIOXIDE AND THE ISOMERIC XYLENES.
J. Am. Chem. Soc. 59, 362-3 (1937); cf. CA 30, 5863
CA 31, 2502

131. Shibler, B. K., and Hovey, M. W.
PROCESSES FOR RECOVERING SULFUR FROM SECONDARY SOURCE MATERIALS.
U. S. Bureau of Mines Info. Circ. 8076 (1962)
TN 1. U56 #8076

132. Slavik, Ivan. (Slovakian Acad. Sci., Bratislava).
THE DECOMPOSITION OF SULFUR DIOXIDE UNDER SULFITE COOKING CONDITIONS.
Svensk Papperslidn. 64, 427-37 (1961) (in German)
CA 55, 21581

133. Smith, Walter T., Jr., and Chen, Wen-Yean.
PREPARATION OF PHENYL N-SULFINYLHYDRAZINES USING DIMETHYLFORMAMIDE-SULFUR DIOXIDE REAGENT.
Trans. Ky. Acad. Sci. 27(1-2), 37-8 (1966)(Eng.)
CA 68, 869512

134. Smedslund, Tor H.
DIMETHYL SULFOXIDE AS SOLVENT FOR SULFUR DIOXIDE.
Finska Kemistsamfundets Medd. 59, 40-3 (1950)
CA 46, 4329

135. Sokol'skii, G. A., and Kuunyants, I. L.
REACTION OF SULFUR TRIOXIDE WITH POLYCHLOROETHYLENES.
Izv. Akad. Nauk SSSR, Ser. Khim. 1965(9), 1655-7 (Russ.)
CA 64, 578

136. Sorokin, V. A., and Puzitzkii, K. V.
REACTIONS BETWEEN BUTADIENE AND SULFUR DIOXIDE.
Sintet. Kauchuk 1933, No. 6, 12-16
CA 28, 3339

137. Squire, J. M., and Waters, William A.
ADDITION OF PHENYL RADICALS TO SULFUR DIOXIDE.
J. Chem. Soc. 1962, 2068-9
CA 57, 8834

138. Sackelberg, M. V., Hoverath, A., and Scheringer, Ch.
THE STRUCTURE OF CLATHRATE COMPOUNDS OF PHENOL.
Z. Elektrochem. 62, 123-30 (1958)
CA 52, 10683

139. Staudinger, H., and Ritzenthaler, B.
HIGHLY POLYMERIZED COMPOUNDS.
CIV. THE ADDITION OF SULFUR DIOXIDE TO ETHYLENE DERIVATIVES.
Ber. 68B, 455-71 (1935); cf. CA 29, 766
CA 29, 3976

140. Stratford, H. W.
SULFONATION WITH SULFUR TRIOXIDE.
U. S. 3, 056, 831 (Cl. 260-505), Oct. 2, 1962
CA 58, 1291

141. Stutzer, A.
DETERMINATION OF SULFUROUS ACID IN WASTE LYES OF THE SULFITE CELLULOSE FACTORIES.
Chem.-Ztg., 34, 1167-8
CA 5, 1335

142. Suter, C. M., Evans, P. B., and Kiefer, James M.
DIOXANE SULFOTRIOXIDE, A NEW SULFATING AND SULFONATING AGENT.
J. Am. Chem. Soc. 60, 538-40 (1938)
CA 32, 3405

143. Suzuki, Hiroyuki.
PARTITION OF SULFUR DIOXIDE BETWEEN WATER AND SOME SOLVENTS IMMISCIBLE WITH WATER.
Bull. Inst. Phys. Chem. Research (Tokyo) 19, 1360-3 (1940)
CA 35, 1292

144. Swisher, E. M.
SO_2-ACETONE AS A HOUSEHOLD FUMIGANT (FOR INSECTS).
J. Econ. Entomol. 37, 694-7 (1944)
CA 39, 568

145. Thomas, T. L., and Clark, E. L.
MOLECULAR SIEVES REDUCE ECONOMIC, OPERATIONAL PROCESS PROBLEMS.
Oil Gas J. 65(12) 112-15 (1967)(Eng.)
CA 67, 4525

146. Timberlake, C. F., and Bridle, P.
FLAVYLIUM SALTS, ANTHOCYANIDINS, AND ANTHOCYANINS. II. REACTIONS WITH SULFUR DIOXIDE.
J. Sci. Food Agr. 18(10), 479-85 (1967)(Eng.)
CA 68, 28494

147. Troitzkii, M., and Rassolenko, L.
DECOMPOSITION OF SODIUM PHENOLATE WITH SULFUR DIOXIDE.
Org. Chem. Ind. (USSR) 1, 272-6 (1936)
CA 30, 6347

148. Ujhidy, Aurel; Babos, Barnabas; and Farady, Laszlo. (Ungar, Akad. Wiss., Veszprem, Hung.).
SULFONATION OF DODECYLBENZENE WITH SULFUR TRIOXIDE-AIR MIXTURE IN A THIN-LAYER REACTOR.
Chem. Tech. (Berlin) 18(11), 652-4 (1966)(Ger.)
CA 67, 18557

149. Vasil'ev, A. M.
THE PROBABLE COMPOSITION OF THE EUTECTICS OF SOME VOLATILE SUBSTANCES.
J. Russ. Phys.-Chem. Soc. 49, 432-41 (1917)
CA 18, 1418

150. Vian, A., Andres, A. Soler, and Fernandez, C. Iriarte.
STABILITY AND HEATS OF FORMATION IN PYRIDINES-SO_2 SYSTEMS OF INDUSTRIAL INTEREST.
Quim. Ind. (Bilbao) 13(2), 47-53(1966)(Span.)
CA 66 19991

151. Weidmann, H., and Roesner, G.
PROCESS FOR THE MANUFACTURE OF PURE SULFUR DIOXIDE.
Ind. Eng. Chem. News Ed. 14, 105 (1936)
Metallges. Periodic Rev. No. 11, 7-13 (1936)
CA 30,. 3595

152. Weissenberger, G., and Hadwiger, H.
THE ABSORPTION OF SULFUR DIOXIDE IN ORGANIC LIQUIDS.
Z. Angew. Chem. 40, 734-6 (1927)
CA 21 3052

153. Weissenberger, G., and Piatti, L.
OBTAINING SULFUR DIOXIDE FROM WASTE GASES WITH THE AID OF CYCLIC KETONES.
Chem.-Ztg. 53, 245-7, 266-7 (1929).
CA 23, 3282

154. Whiting, R. P., Others
ON MECHANISM OF SULPHUR DIOXIDE ABSORPTION IN AQUEOUS MEDIA.
Tappi 36(4), 172-5 (April 1953)
Eng. Index 1953 p. 1069

155. Wynne-Jones, W. F. K., and Anderson, A. R.
THE THERMODYNAMIC CONDITIONS FOR THE FORMATION AND THE EXISTENCE OF CLATHRATE COMPOUNDS.
Compt. Rend. Reunion Ann. Avec. Comm. Thermodynam., Union Intern. Phys. (Paris) 1952
CA 48, 34

156. Yushkevich, J. F., Karzhavin, V. A., Avdeeva, A. V., and Nikol'skaya, Yu. P.
THE PREPARATION OF SULFUR FROM SULFUR DIOXIDE. VIII. THE REACTION OF SULFUR DIOXIDE WITH HYDROCARBONS.
J. Chem. Ind. (Moscow) 1934, No. 2, 33-7; cf. CA 28. 1474
CA 28, 3844

157. Agren, Per.
RECOVERY OF SULFUR FROM GASES CONTAINING SULFUR DIOXIDE.
Svensk Papperstidn. 39, 470-82(1936).–
CA 31: 2756^3 (1937)

158. Anon.
LIQUID SULPHUR FROM COLESHILL ALKAZID PLANT.
Indus Chemist v 40 n 1 Jan 1964, p. 9-12.
Eng. Index 1964, p. 2064

159. Anon.
PILOT PLANT ABSORBS SULFUR IN STATION STACK GASES.
Elec World v 168 n 15 Oct 9 1967, p. 29-30.
Eng. Index Mi 68 p. 93

160. Anon.
POLLUTION CONTROL- AND BYPRODUCT SULFUR TOO.
Eng. and Mining J. 169: 91-100 (June 1968)

161. Anon.
PROGRESS IN DEVELOPMENT OF PROCESSES FOR LIQUID REMOVAL OF HYDROGEN SULPHIDE.
Gas World v 158 n 4140-4141 Dec 21-28 1963, p. 822, 826-7, 829-31.
Eng. Index 1964, p. 720

162. AVCO Space Systems Division
REMOVAL OF SO_2 FROM FLUE GAS. FINAL REPORT.
PB 177, 492 (Nov. 1, 1967)

163. Benny, J. C.
SULFUR DIOXIDE RECOVERY.
Pulp Paper Mag. Can. 46, 598(1945).
CA 39: 4483^4 (L)

164. Biryukova, L. V., Ovcharenko, V. G., Mironov, A. M., Karabaev, A. A.
ISPYTANIE FORSUNOK I RAZBRYZGIVAYUSHCHIKH USTROISTV, PRIMENYAEMYKH DLYA OROSHENIYA V ABSORBERAKH.
Khimicheskaya Promyshlennost n 6 June 1963, p. 64-8.
Eng. Index 1964, p. 2

165. Blomen, T.
ROSENBLAD SYSTEM FOR RECOVERY OF HEAT AND SULFUR DIOXIDE IN THE CHEMICAL WOOD-PULP INDUSTRY.
Tech. Assoc. Papers 20, 346-8(June, 1937); Paper Trade J. 105, No. 13, 52-4.
CA 31: 8919^7 (L)

166. Bloomfield, B. D.
CONTROL OF GASEOUS POLLUTANTS.
Heating, Piping, Air Cond. 40 (1), 195-206 (Jan. 1968).
APCA ABS June 68, No. 9813

167. Bloomfield, B. D.
COSTS, EFFICIENCIES, AND UNSOLVED PROBLEMS OF AIR POLLUTION CONTROL EQUIPMENT.
Air Pollution Control Assn–J v 17 n 1 Jan 1967, p. 28-32.
Eng. Index July 67, p. 5

168. Bondarenko, I. P., and Zemskaya, E. Kh.
INFLUENCE OF TEMPERATURE ON PERFORMANCE OF ARSENIC-SODA SULPHUR REMOVAL PLANT.
Coke and Chem USSR (English translation of Koks I Khimiya) n 6 1965, p. 53-4.

169. Brief, R. S., and Oiestad, A.
IMPINGEMENT BAFFLE PLATE SCRUBBER FOR FLUE GAS.
Air Pollution Control Assn–J v 14 n 9 Sept 1964, p. 372-7.
Eng. Index 1965, p. 803

170. Broman, C. U., and Iseli, R. R..
THE CONTROL OF OPEN HEARTH STACK EMISSIONS WITH VENTURI TYPE SCRUBBERS.
Industrial Heating June 1968, p. 1085-96

171. Chashchin, I. P. (Polytech. Inst., Tomsk).
EFFECT OF FIN HEIGHT AND SPACING ON HEAT TRANSFER AND HYDRAULIC RESISTANCE OF A HEAT EXCHANGER.
Izv. Vysshikh Uchebn. Zavedenii, Khim, i Khim. Tekhnol. 8(4), 674-9(1965)(Russ).
CA 64: 3070g

172. Chedd, G.
FERTILIZER FROM FLUE GASES?
New Scientist (London) 36 (569), 281-3 (Nov. 1967).
APCA 1968, No. 9591

173. Chute, A. E.
LARGE SULPHUR RECOVERY UNITS.
European Chem. News Large Plant Supplement (London) 21-3 (Sept. 30, 1966).
APCA 1967, No. 7947

174. Coykendall, J. W., Spencer, E. F., and York, O. H.
NEW HIGH-EFFICIENCY MIST COLLECTOR.
J. Air Poll. Control Assoc. 18 (5), 315-18 (May 1968).
APCA ABS June 68, No. 9815

175. Csathy, D.
EVALUATING BOILER DESIGNS FOR PROCESS-HEAT RECOVERY.
Chem Eng v 74n 12 June 5 1967, p. 117-24.
Eng. Index 1967, p. 26

176. Davies, G. A., Ponter, A. B., and Craine, K.
DIFFUSION OF CARBON DIOXIDE IN ORGANIC LIQUIDS.
Can J Chem Eng v 45 n 6 Dec 1967, p. 372-6.
Eng. Index April 68, p. 62-3

177. Dillon, G. B., and Harris, I. J.
DETERMINATION OF MASS TRANSFER COEFFICIENTS AND INTERFACIAL AREAS IN GAS-LIQUID CONTACTING SYSTEMS.
Can J Chem Eng v 44 n 6 Dec 1966, p. 307-12.
Eng. Index July 1967, p. 29

178. Donovan, J. R., and Stuber P. J.
SULFURIC ACID PRODUCTION FROM ORE ROASTER GASES.
J of Metals v 19 n 11 November 1967, p. 45-50.
Eng. Index March 1968, p. 263

179. Douglas, H. R., Snider, I. W. A., and Tomlinson, II, G. H.
TURBULENT CONTACT ABSORBER.
Chem Eng Progress v 59 n 12 December 1963, p. 85-9.
Eng. Index 1964, p. 2

180. Eckert, J. S., Foote, E. H., Rollison, L. R., and Walter, L. F.
ABSORPTION PROCESS UTILIZING PACKED TOWERS.
Indus and Eng Chem v 59 n 2 February 1967, p. 41-7.
Eng. Index June 1967, p. 1

181. Field, J. H., Kurtzrock, R. C., and McCrea, D. H.
HOW TO PREVENT SO_2 EMISSION.
Chem. Eng. 74 (13), 158-60 (June 19, 1967).
APCA 1967 No. 8671

182. Field, J. H., Benson, H. E., Johnson, G. E., Tosh, J. S., and Forney, A. J.
PILOT-PLANT STUDIES OF HOT-CARBONATE PROCESS FOR REMOVING CARBON DIOXIDE AND HYDROGEN SULFIDE.
U S Bur Mines–Bul 597 1962, 44 p.
Eng. Index 1962, p. 504

183. Francis, Wilfred.
REMOVAL OF SULFUR COMPOUNDS FROM INDUSTRIAL GASES.
Engineering 172, 180-2(1951).
CA 46: 1708

184. Frankenberg, T. T.
REMOVAL OF SULFUR FROM FUELS AND PRODUCTS OF COMBUSTION.
ASME–Paper 64-WA/APC-2 for meeting Nov 29-Dec 4 1964, 12 p.
Eng. Index 1965, p. 45

185. Fuchs, O.
NEW DEVELOPMENTS IN GAS-SCRUBBING PROCESSES.
Gas-u. Wasserfach 80, 18-24(1937).
CA 31: 1985^5 (L)

186. Fuquay, J. J.
METEOROLOGICAL FACTORS IN THE APPRAISAL AND CONTROL OF ACUTE EXPOSURES TO STACK EFFLUENTS.
Second U. N. International Conference on Peaceful Uses of Atomic Energy, 18: 272-79. (1958).

187. DEVELOPMENT OF TWO-PHASE CONTACTOR WITHOUT PRESSURE DROP.
B. GAL-OR. A.I.Ch.E. J v 12 n 3 May 1966, p. 604-5.
Eng. Index 1966, p. 356

188. Galeano, S. F., and Harding, C. I.
SULFUR DIOXIDE REMOVAL AND RECOVERY FROM PULP MILL POWER PLANTS.
Air Pollution Control Assn –J v 17 n 8 Aug 1967, p. 536-9.
Eng. Index January 1968, p. 7

189. Ganz, S. N., and Kuznetsov, I. E.
DESIGN OF OPEN EQUAL-FLOW TOWERS WITH CENTRIFUGAL SPRAYERS.
Int Chem Eng v 5 n 4 Oct 1965, p. 653-6.
Eng. Index 1966, p. 386

190. Ganz, S. N., Kuznetsov, I. E., and Lokshin, M. A.
DETERMINATION OF SIZE OF HOLLOW SCRUBBERS FOR REMOVING HYDROGEN SULPHIDE FROM COKE-OVEN GAS.
Coke and Chem USSR (English translation of Koksi Khimiya) n 9 1964, p. 46-8.
Eng. Index 1965, p. 387

191. Grenier, P.
SOLVENT COUNTER-DIFFUSION IN GAS ABSORPTION.
Can J Chem Eng v 44 n 4 August 1966, p. 213-16.
Eng. Index April 1967, p. 1

192. Guentheroth, H.
NEUERE ERFAHRUNGEN MIT VENTURI-SCRUBBERN FUER DIE FEINSTREINIGUNG VON GASEN IM KOKEREIBETRIEB.
Deutsche Gesellschaft fuer Chemisches Apparatewesen–DECHEMA Monographien v 48 n 835-858 1963, p. 329-45.
Eng. Index 1965, p. 858

193. Haley, H. E.
SO_2 REMOVAL PROCESS PROMISES CLEANER AIR.
Elec. World 167 (20), 71-5 (May 15, 1967).

194. Hamberg, Marvin. (Atlantic Refining Co., Philadelphia, Pa.).
USER LOOKS AT BRAZED ALUMINUM PLATE-FIN EXCHANGER.
Proc. Am. Petrol. Inst. Sect. III 43, 180-94(1963).
CA 61: 12964f

195. Hangebrauck, R. P., and Spaite, P. W.
STATUS REPORT ON CONTROLLING OXIDES OF SULFUR.
Air Pollution Control Assn–J v 18 n 1 January 1968, p. 5-8.
Eng. Index April 1968, p. 4

196. Hanhart, J., Kramers, H., and Westerterp, K. R.
RESIDENCE TIME DISTRIBUTION OF GAS IN AGITATED GAS-LIQUID CONTACTOR.
Chem Eng Science v 18 n 8 August 1963, p. 503-9.
Eng. Index 1963, p. 277

197. Harris, E. R., and Beiser, F. R.
CLEANING SINTER PLANT GAS WITH VENTURI SCRUBBER.
Air Pollution Control Assn–J v 15 n 2 February 1965, p. 46-9.
Eng. Index 1965, p. 803

198. Hartmann, F., and Roeck, G.
ABSORPTIONSVERSUCHE MIT CINEM BLASENWASCHER.
Chemic-Ingenieur-Technik v 37 n 3 March 1965, p. 214-18.
Eng. Index 1966, p. 2

199. Hellstrom, Arne G.
USE OF ABSORPTION TOWERS FOR RECOVERY OF PRESSURE RELIEF GASES.
Pulp Paper Mag. Can. 47, No. 3, 119-22(1946).
CA 40: 4516^{9} (L)

200. Hensinger, C. E., Wakefield, R. E., and Claus, K. E.
TURNING POLLUTION GASES INTO PROFITS.
Eng. Mining J. 169 (2), 131-5 (February 1968).
APCA ABS June 1968, No. 9823

201. Hollis, O. L.
SEPARATION OF GASEOUS MIXTURES USING POROUS POLYAROMATIC POLYMER BEADS.
Analytical Chem v 38 n 2 February 1966, p. 309-16.
Eng. Index 1966, p. 3

202. Jameson, G. J.
SOME OPERATING CHARACTERISTICS OF RESONANT BUBBLE CONTACTOR.
Instn Chem Engrs–Trans v 44 n 3 1966, p. T91-8.
Eng. Index 1966, p. 3

203. Johnstone, H. F., and Roberts, M. H.
DEPOSITION OF AEROSOL PARTICLES FROM MOVING GAS STREAMS.
Industrial and Engineering Chemistry, 41 (11): 2417-23 (1949).
CA 44: 2674e.

204. Johnstone, H. F., and Silcox, H. E.
GAS ABSORPTION AND HUMIDIFICATION IN CYCLONE SPRAY TOWERS.
Industrial and Engineering Chemistry, 39 (7): 808 (1947).
CA 41: 4971^8.

205. Johnstone, H. F., and Singh, A. D.
RECOVERY OF SULFUR DIOXIDE FROM WASTE GASES.
Industrial and Engineering Chemistry, 29 (3): 286-97 (1937).
CA 31: 3743^4.

206. Johswich, F.
SULFUR REMOVAL FROM FLUE GASES–IMPORTANCE AND POSSIBILITIES.
Brennstoff Waermekraft 14, No. 3, 105-15(1962).
CA 57: 3745

207. Johswich, F.
UEBER DEN DERZEITIGEN STAND DER ABGASENTSCHWEFELUNG.
Brennstoff-Waerme-Kraft v 17 n 5 May 1965, p. 238-45; see also English translation in Combustion v 37 n 4 October 1965, p. 18-26.
Eng. Index 1965, p. 803

208. Jones, W. P.
DEVELOPMENT OF THE VENTURI SCRUBBER.
Industrial and Engineering Chemistry, 41 (11): 2424-7 (1949).
CA 44: 1762f

209. Jordan, W. von.
VENTURI- UND RADIALSTROM-WAESCHER ZUR KUEHLUNG UND REINIGUNG VON NUTZ- UND ABGASEN.
Stahl u Eisen v 86 n 7 April 7 1966, p. 399-406.
Eng. Index 1966, p. 1081

210. Katell, S., and Plants, K. D.
HERE'S WHAT SO_2 REMOVAL COSTS.
Hydrocarbon Processing v 46 n 7 July 1967, p. 161-4.
Eng. Index December 1967, p. 7

211. Katell, S.
REMOVING SULFUR DIOXIDE FROM FLUE GASES.
Chem Eng Progress v 62 n 10 October 1966, p. 67-73.
Eng. Index April 1967, p. 79

212. Khanin, I. M., Yakovlev, V. I., and Kartsynel, M. B.
SPRAY-TYPE BENZOLE SCRUBBER WITH RADIALLY-SLOTTED GAS DISTRIBUTORS.
Coke and Chem USSR (English translation of Koks i Khimiya) n 1 1965, p. 30-5.
Eng. Index 1965, p. 858

213. Kielback, A. W.
DEVELOPMENT OF FLOATING-BED SCRUBBERS.
Chem Eng Progress Symposium Ser v 57 n 35 1961, p. 51-4.
Eng. Index 1962, p. 504

214. Kim, J. C., and Molstad, M. C.
FIGURE OPTIMUM ABSORPTION DESIGN.
Hydrocarbon Processing v 45 n 12 December 1966, p. 107-8.
Eng. Index September 1967, p. 1

215. Klimecek, R., Skrivanek, J., and Bettelheim, J.
BEITRAG ZUR ENTSCHWEFELUNG VON RAUCHGASEN.
Staub–Reinhaltung der Luft v 26 n 6 June 1966, p. 235-8.
Eng. Index July 1967, p. 29

216. Kochergin, N. A., Kaganskii, I. M., Shul'ts, E. Z.
PRIMENENIE KOLONN S DYRCHATRYMI PROVAL'NYMI TARELKAMI DLYA OCHISTKI GAZA OT DVUOKISI UGLERODA RASTVOROM MONOETANOLAMINA.
Khimicheskaya Promyshlennost n 11 Nov. 1963, p. 66-9.
Eng. Index, 1964, p. 2

217. Kostin, V. M.
GIDRAVLICHESKOE SOPROTIVLENIE OROSHAEMOI NASADKI PRI PRYAMOTOCHNOM DVIZHENII GAZA I ZHIDKOSTI.
Khimicheskaya Promyshlennost n 10 Oct. 1964, p. 11-13.

218. Lagakos, J.
VENTURI SCRUBBERS FOR SMALL FOUNDRY CUPOLAS.
Foundry 96(1), 70-3 (Jan. 1968)
APCA: 1968, No. 9415

219. Leventsov, A. N.
NOVAYA KONSTRUKTSIYA TSENTROBEZHNOGO MNOGOSTUPENCHATOGO RASPYLITELYA.
Khimicheskoe i Neftyanoe Mashinostroenie n 9 Sept. 1966, p. 15-17.
Eng. Index, Feb. 1968, p. 38

220. Litvinov, A. T.
O GIDRAVLICHESKOM SOPROTIVLENII I EFFEKTIVNOSTI DEISTVIYA TURBULENTNOGO PROMYVATELYA.
Khimicheskaya Promyshlennost n 8 Aug. 1964, p. 64-9.
Eng. Index, 1966, p. 1081

221. Lunde, K. E.
PERFORMANCE OF EQUIPMENT FOR CONTROL OF FLUORIDE EMMISSIONS.
Industrial and Engineering Chemistry, 50(3); 293-8 (1958)
CA 52: 13335a.

222. Matrozov, V. I., Ramm, V. M., Chagina, Z. V.
ISSLEDOVANIE VYSOKOSKOROSTNYKH PRYAMOTOCHNYKH RASPYLITEL'NYKY APPARATOV PRI ABSORBTSIIKHOROSHO RASTVORIMYKHGAZOV.
Khimicheskaya Promyshlennost n 2 Feb. 1965, p. 46-53.
Eng. Index, 1966, p. 2

223. Miller, D. M., Jonakin J.
KANSAS P&L TO TRAP SULFUR WITH FLUE-GAS SCRUBBER.
Electrical World March 4, 1968, p. 35-6.

224. Morton, F., King, P. J., McLaughlin, A.
HELICAL-COIL DISTILLATION COLUMNS.
Instn Chem Engrs-Trans v 42 n 8 1964 p.T285-T304.
Eng. Index, 1965, p. 551

225. Nakai, Y. and Yokogawa, T.
THE STUDY OF MULTI-PURPOSE GAS ABSORBER BY WET PROCESS.
[Chem. Ind.] Kagaku Kōgyō (Tokyo) 18 (12), 1228-35 (Dec. 1967).

226. Nevins, J. W.
FINNED TUBE EXCHANGERS SOLVE WIDE VARIETY OF HEAT TRANSFER PROBLEMS.
Power v 109 n 7 July 1965 p. 62-5.
Eng. Index, 1965, p. 992

227. Nicklin, T., Holland, B. H.
FURTHER DEVELOPMENTS IN STRETFORD PROCESS.
Gas World v 158 n 4125 Sept. 7, 1963, p. 273-8.
Eng. Index, 1964, p. 720

228. Nicklin, T., Brunner, E.
HOW STRETFORD PROCESS IS WORKING.
Petroleum Refiner v 40 n 12 Dec. 1961, p. 141-6.
Eng. Index, 1962, p. 504

229. Nicklin, T., Holland, B. H.
REMOVAL OF HYDROGEN SULPHIDE FROM COKE OVEN GAS BY STRETFORD PROCESS.
Deutsche Gesellschaft fuer Chemisches Apparatewesen-DECHEMA Monographien v 48 n 835-858 1963, p. 243-71.
Eng. Index, 1965, p. 858

230. O'Brien, N. G. and Turner, R. L. (E. I. du Pont de Nemours & Co., Wilmington, Del.).
FIN THERMAL EFFICIENCY DURING SIMULTANEOUS HEAT- AND MASS-TRANSFER.
A.I.Ch.E. (Am. Inst. Chem. Engrs.) J. 11(3), 546-8(1965)(Eng).
CA 63: 5257c

231. Oldshue, J. Y.
MIXING
Indus & Eng Chem v 59 n 11 Nov. 1967, p. 58-70.
Eng. Index, April 1968, p. 32

232. Ostergaard, K., Theisen, P. I.
EFFECT OF PARTICLE SIZE AND BED HEIGHT ON EXPANSION OF MIXED PHASE (GAS-LIQUID) FLUIDIZED BEDS.
Chem Eng Science v 21 n 5 May 1966, p. 413-17.
Eng. Index, Feb. 1967, p. 31

233. Otsubo, S., Sanuki, Y., Yamamoto, T., Nakazono, I., Haruta, M.
OPERATION OF NEWLY INSTALLED LURGI VENTURION TYPE BLAST FURNACE GAS PRECIPITATOR.
Yawata Tech Report n 249 Dec. 1964, p. 5524-31.
Eng. Index, 1965, p. 858

234. Pasternak, R.
NEUE VERFAHREN DER H_2S- AND CO_2-ENTFERNUNG AUS GASEN.
Gas- u Wasserfach v 103 n 17 Apr. 27, 1962, p. 417-18.
Eng. Index, 1962, p. 504

235. Plit, I. G.
ABSORBTSIYA DVUOKISI UGLERODA RASTVOROM MONOETANOLAMINA V SKRUBBERE S PUL'VERIZATSIONNO-FORSUNOCHNOI TARELKOI.
Khimicheskaya Promyshlennost n 5 May 1963, p. 57-61.
Eng. Index, 1964, p. 1

236. Plit, I. G.
PUL'VERIZATSIONNYI SKRUBBER-DEKARBONIZATOR.
Khimicheskaya Promyshlennost n 8 Aug. 1964, p. 61-4.
Eng. Index, 1966, p. 1081

237. Plumley, A. L., et al.
REMOVAL OF SO_2 AND DUST FROM STACK GASES.
Proc. American Power Conf. Vol. 29: 592-614 (1967)
TJ5. A55 (1967)

238. Pollock, W. A., Tomany, J. P. and Frieling, G. G.
FLUE-GAS SCRUBBER.
Mech Eng. 89 (8), 21-5 (Aug. 1967).
PCA 1967, No. 8683

239. Pollock, W. A., Frieling, G., Tomany, J. P.
REMOVAL OF SULFUR DIOXIDE AND FLY ASH FROM COAL BURNING POWER PLANT FLUE GASES.
ASME-Paper 66-WA/CD-4 for meeting Nov. 27-Dec. 1, 1966, 8 p.
Eng. Index April 1967, p. 79

240. Porter, K. E.
EFFECT OF CONTACT-TIME DISTRIBUTION ON GAS ABSORPTION WITH CHEMICAL REACTION.
Instn Chem Engrs-Trans v 44 n 1 1966 p. T25-36.
Eng. Index 1966, p. 2

241. Pozin, M. E., Tarat, E. Ya., Tereshchenko, L. Ya., Orekhov, I. J.
ABSORBTSIYA SEROVODORODA MYSH'YAKOVO-SODOVYM RASTVOROM PRI TURBULENTONOM (PENNOM) REZHIME.
Zhurnal Prikladnoi Khimil v 39 n 8 Aug. 1966, p. 1712-19; see also English translation in J Applied Chem of USSR v 39 n 8 Aug. 1966, p. 1601-7.
Eng. Index, Oct. 1967, p. 89

242. Roesner, Gerhard
UTILIZATION OF INDUSTRIAL GASES AND WASTE GASES BY THE LURGI PROCESSES.
Metallges. Periodic Rev. No. 13, 22-30 (1938).
CA 32: 5104^{7}

243. Rosenblad, C. v.
HEAT AND SULFUR DIOXIDE RECOVERY (IN SULFITE MILLS) WITH AND WITHOUT HEAT EXCHANGERS.
Zellstoff u. Papier 19, 205-9(1939).
CA 33: 6591^{1} (L)

244. Rosenblad, C.
RECOVERY OF HEAT AND SULFUR DIOXIDE GAS IN THE SULFITE-PULP INDUSTRY WITH OR WITHOUT HEAT EXCHANGERS.
Paper Trade J. 106, No. 26, 78-81(1938).
CA 32: 8135^{8} (L)

245. Ross, T. K., Coombe, A. J.,
GAS ABSORPTION IN MULTIPLE LIQUID-JET CONTACTOR.
Instn Chem Engrs-Trans v 44 n 5 1966 p. T160-5.
Eng. Index, Jan. 1967, p. 93

246. Ruckenstein, E., Smigelschi, O.
THERMAL THEORY AND PLATE EFFICIENCY.
Can J Chem Eng v 45 n 6 Dec. 1967, p. 334-40.
Eng. Index, April 1968, p. 47

247. Ryason, P. R., Harkins, J.
STUDIES ON NEW METHOD OF SIMULTANEOUSLY REMOVING SULFUR DIOXIDE AND OXIDES OF NITROGEN FROM COMBUSTION GASES.
Air Pollution Control Assn-J v 17 n 12 Dec. 1967, p. 796-9.
Eng. Index, March 1968, p. 93

248. Rylek, M., Standart, G.
HYDRAULICS OF SLEVE TRAYS.
Int Chem Eng v 4 n 4 Oct. 1964, p. 711-47.
Eng. Index, 1965, p. 551

249. Shah, I. S.
NEW EVAPORATOR-SCRUBBER SYSTEMS IMPROVE KRAFT RECOVERY PROCESS.
Paper Trade J. 152 (12), 58-64 (Mar. 18, 1968).
APCA June 1968, No.9832

250. Sharma, M. M.
KINETICS OF REACTIONS OF CARBONYL SULPHIDE AND CARBON DIOXIDE WITH AMINES AND CATALYSIS BY BROENSTED BASES OF HYDROLYSIS OF COS.
Faraday Soc-Trans v 61 n 508 April 1965, p. 681-8.
Eng. Index, 1966, p. 2

251. Shibler, B. K., Hovey, M. W.
PROCESSES FOR RECOVERING SULFUR FROM SECONDARY SOURCE MATERIALS.
U.S. Bur Mines-Information Cir 8076 1962, 62 p.
Eng. Index, 1962, p. 1375

252. Shnyakin, A. I., Ermolaev, V. N.
K VOPROSU O TEKHNOLOGII OCHISTKI DOMENNOGO GAZA I KONSTRUKTSII SKRUBBEROV.
Stal n 2 Feb. 1963, p. 176-8; see also English translation in Stal in English n 2 Feb. 1963, p. 152-4.
Eng. Index, 1963, p. 786

253. Slesser, C. G. M., Highet, J.
TRANSFER UNIT MODEL OF SLURRIED BED REACTOR.
Brit Chem Eng v 11 n 4 April 1966, p. 247-52.
Eng. Index, Feb. 1967, p. 31

254. Slobodyanik, I. P.
TESTS ON RING-SHAPED JET PLATE.
Chem & Technology of Fuels & Oils (English translation of Khimiya i Tekhnologiya Topliv i Masel) n 1 Jan. 1966, p. 43-6.
Eng. Index, Oct. 1967, p. 54

255. Smith, E. C., Gunter, A. Y., Victory, S. P., Jr. (Hudson Eng. Corp., Houston, Tex.).
FIN TUBE PERFORMANCE.
Chem. Eng. Progr. 62(7), 57-67(1966)(Eng).
CA 65: 10155b

256. Squires, A. M.
AIR POLLUTION: THE CONTROL OF SO_2 FROM POWER STACKS. PART II. THE REMOVAL OF SO_2 FROM STACK GASES.
Chem. Eng. 74 (24), 133-40 (Nov. 20, 1967).
APCA ABS 1968, No. 9260

257. Srinivasan, P. R., Gururaja, J., Ramachandran, A.
ISOTHERMAL PRESSURE DROP ALONG TRANSVERSE, TRANSVERSE HELICAL & INCLINED FINS IN CIRCULAR ANNULI.
Indian J Technology v 3 n 4 April 1965, p. 103-10.
Eng. Index, 1965, p. 992

258. Potter, O. E., Sinclair, R. J., Stephens, G. K.
GAS EXCHANGE BETWEEN BUBBLES AND DENSE PHASE IN FLUIDISED BED.
Powder Technology v 1 n 3 Oct. 1967, p. 157-66.
Eng. Index, April 1968, p. 32

259. Swartz, J. N.
SULFITE BLOW HEAT AND GAS RECOVERY.
Pulp Paper Mag. Can. 44, 139-42(1943)
CA 37: 2173^6 (L)

260. Tarat, E. Ya., Bogatykh, S. A.
OPERATION OF FOAM APPARATUS AT ELEVATED GAS PRESSURES.
Chem & Petroleum Eng (English translation of Khimicheskoe i Neftyanoe Mashinostroenie) n 4 April 1965, p. 278-81.
Eng. Index, 1966, p. 3

261. Terres, Ernst, Buscher, Hanna, and Matroff, Georg.
THE REACTIONS INVOLVED AND THE REACTION VELOCITIES FOR THE REGENERATION OF THE SCRUBBING SOLUTIONS IN THE METAL THIONATE PROCESSES FOR PURIFYING COAL GAS FROM AMMONIA AND HYDROGEN SULFIDE. A MANGANESE SULFATE PROCESS.
Brennstoff-Chem. 35, 144-51(1954); ef. ivid. 65-74, 119-20.

262. Thomas, B. E.
OPERATING STRETFORD PURIFICATION PLANT.
Gas J v 317 n 5243 March 11, 1964, p. 283-5; see also Gas World v 159 n 4157 April 18, 1964, p. 520-2.
Eng. Index, 1964, p. 720

263. Thomas, M. O., Hill, G. R., and Abersold, J. N.
DISPERSION OF GASES FROM TALL STACKS.
Industrial and Engineering Chemistry, 41(11): 2709 (1949).
CA 44: 2144e

264. Timberlake, R. C.
FLUORINE SCRUBBER.
Southern Eng. 85 (6), 62-4 (June 1967).
APCA 1968, No. 9616

265. Todd, W. G., Van Winkle, M.
ENTRAINMENT AND PRESSURE DROP WITH JET TRAYS IN AIR-WATER SYSTEM.
Indus & Eng Chem-Process Design & Development v 6 n 1 Jan. 1967, p. 95-101.
Eng. Index, July 1967, p. 25

266. Towell, G. D., Strand, C. P., Ackerman, G. H.
MIXING AND MASS TRANSFER IN LARGE DIAMETER BUBBLE COLUMNS.
A.I.Ch.E.-Inst Chem Engrs-10. Mixing-Theory Related to Practice-Paper 10.10 for meeting London, June 13-17 1965, p. 91-100.
Eng. Index, 1966, p. 3

267. Vlcek, V., Vavra, V., Stary, M.
OPTIMIZATION OF CONDITIONS FOR FOAM-PHASE ABSORPTION OF SULFUR TRIOXIDE.
Int Chem Eng v 2 n 2 April 1962, p. 216-20.
Eng. Index, 1962, p. 1376

268. Walker, A. B., Hall, R. M.
OPERATING EXPERIENCE WITH A FLOODED DISC SCRUBBER-A NEW VARIABLE THROAT ORIFICE CONTACTOR.
J. Air Poll. Control Assoc. 18 (5), 319-23 (May 1968).
APCA: June 1968, No. 9837

269. Wallis, E.
RECOVERY OF SULPHUR IN MARKETABLE FORM FROM FLUE GASES.
Brit Chem Eng v 7 n 11 Nov. 1962, p. 833-6.
Eng. Index, 1963, p. 740

270. Weissbach, H.
KOELNER FRUEHJAHRSMESSE 1966-ALLGASGERAETE AUF BREITER FRONT.
Gas- u Wasserfach v 107 n 21 May 27, 1966, p. 586-92; see also English summary in Gas J v 327 n 5367 Aug. 17, 1955, p. 171.
Eng. Index, Oct. 1967, p. 89

271. Westerterp, K. R.
DESIGN OF AGITATORS FOR GAS-LIQUID CONTACTING.
Chem Eng Science v 18 n 8 Aug. 1963, p. 495-502.
Eng. Index, 1963, p. 277

272. Calvert, S., Workman, W. L.
MASS TRANSFER IN SUPPORTED FROTHS.
A.I.Ch.E. J v 12 n 5 Sept. 1966, p. 867-76.
Eng. Index, June 1967, p. 33

273. Zalogin, N. G. and Semlyanskii, G. I.
THE REDUCTION OF THE SIZE OF SCRUBBERS AND THE SAVING OF ELECTRICAL ENERGY IN THE REMOVAL OF S OXIDES FROM FLUE GAS BY THE LIME METHOD.
Izvest. Vsesoyuz. Teplotekh. Inst. 14, No. 2, 19-23 (1941);
Chem. Zentr. 1943, I, 1128.
CA 38: 4119^6 (L)

274. Zinov'eva, A. P., Bashkirova, S. G.
EFFICIENCY OF CONTACT BETWEEN HETEROGENEOUS PHASES AND DEGREE OF CHEMICAL CONVERSION IN FLUIDIZED BED.
Chem & Technology of Fuels & Oils (English translation of Khimiya i Tekhnologiya Topliv i Masel) n 2 Feb. 1967, p. 77-81.
Eng. Index, March 1968, p. 35

PATENTS

275. Austrian 174,896 (May 11, 1953)
RECOVERY OF CARBON DIOXIDE AND SULFUR DIOXIDE FROM COMBUSTION GASES.
Bodoni & Co., G. m. b. H. (Desider Bodoni, inventor)
CA 47, 7750

276. Belg. 670,775 (April 12, 1966)
U. S. Appl. Oct. 13, 1964, and Jan. 25, 1965
NEW SOLVENT ELECTROLYTE SYSTEMS FOR ELECTROCHEMICAL CELLS.
American Cyanamid Co. (Arthur K. Hoffmann)
CA 67, 25473

277. Brit., 2,719 (Feb. 6, 1908)
FOR OBTAINING S FROM SO_2 AND H_2S.
14 Hauptstrasse, Zehlendorf, Ger. (Walther Feld)
CA 3, 1330

278. Brit., 11,635 (May 11, 1914)
ADDITION PRODUCTS OF OLEFIN HYDROCARBONS WITH SULFUR DIOXIDE.
(F. E. Mathews, and H. M. Elder)
CA 9, 2971

279. Brit., 107,589 (June 26, 1917)
SULFUR DIOXIDE.
(M. Kaltenbach)
CA 11, 2948

280. Brit., 159,337 (Dec. 2, 1919)
SULFUR DIOXIDE.
(P. Pascal)
CA 15, 2161

281. Brit., 267, 071 (March 5, 1926)
MULTIPLE-EFFECT EVAPORATING APPARATUS FOR RECOVERY OF SULFUR DIOXIDE USED IN LIQUID FORM FOR REFINING HYDROCARBON OILS.
Allgemeine Ges. Fur Chemische Industrie
CA 22, 865

282. Brit., 371,888 (Apr. 29, 1932)
SULFUR DIOXIDE.
John S. Dunn and Imperial Chemical Industries Ltd.
CA 27, 3787

283. Brit., 400,998 (Nov. 6, 1933)
SULFUR DIOXIDE
Daniel Tyrer and Imperial Chemical Industries Ltd.
CA 28, 2135

284. Brit., 450,519 (July 20, 1936)
RECOVERING WEAK GASEOUS ACIDS.
I. G. Farbenindustrie A.-G.
CA 31, 223

285. Brit., 457,343 (Nov. 26, 1936)
REMOVING WEAK GASEOUS ACIDS FROM GASES.
I. G. Farbenindustrie A.-G.
CA 31, 3245

286. Brit., 467,579 (June 17, 1937)
RECOVERING WEAK GASEOUS ACIDS FROM GASES.
I. G. Farbenindustrie A.-G.
CA 31, 8894

287. Brit., 468,972 (July 16, 1937)
RECOVERING ACIDIC GASES FROM GAS MIXTURES.
Robinson Brothers Ltd. (Deric W. Parkes and Richard B. Evans)
CA 32, 755

288. Brit., 470,440 (Aug. 16, 1937)
RECOVERING WEAK GASEOUS ACIDS FROM GASES.
I. G. Farbenindustrie A.-G.
CA 32, 1078

289. Brit., 484,714 (May 10, 1938)
RECOVERING SULFUR DIOXIDE.
Board of Trustees of the University of Illinois
CA 32, 8087

290. Brit., 506,002 (May 19, 1939)
RECOVERING SULFUR DIOXIDE.
Imperial Chemical Industries Ltd.
CA 33, 9561

291. Brit., 523,845 (July 24, 1940)
SULFUR DIOXIDE RECOVERY.
Murray Guggenheim, (Solomon R. Guggenheim, Elias A. C. Smith, and Medley G. B. Whelpley)
CA 35, 6400

292. Brit., 534,935 (March 24, 1941)
MORPHOLINE COMPOUNDS.
Harris-Seybold-Potter Co.
CA 36, 1334

293. Brit., 564,734 (Oct. 11, 1944)
RECOVERING SULFUR DIOXIDE FROM A GAS MIXTURE.
American Smelting & Refining Co.
CA 40, 3577

294. Brit., 675,831 (July 16, 1952)
SOLUTIONS OF SULFUR DIOXIDE.
Societe Anon. Des Manufactures Des Glaces Et Produits Chimiques De Saint-Gobain, Chauny Et Cirev.
CA 46, 11608

295. Brit., 692,804 (June 1953)
PURIFICATION OF SYNTHESIS AND FUEL GASES.
Gesellschaft Fur Linde's Eismaschinen A. G. and Lurgi Gesellschaft Fur Warmetechnik M. B. H.
CA 48, 1657

296. Brit., 734,577 (Aug. 3, 1955)
PURIFICATION OF SYNTHESIS AND FUEL GASES.
Gesellschaft Fur Linde's Eismaschinen A. G. and Lurgi Gesellschaft Fur Warmetechnik M. B. H.
CA 50, 1292

297. Brit., 901,272 (July 18, 1962)
PURIFICATION OF FUEL GASES.
Metallgesellschaft A-G.
CA 57, 12808

298. Brit., 983,391 (Feb. 17, 1965/Appl. May 27, 1960)
REMOVAL OF VOLATILE SULFUR COMPOUNDS FROM FUEL GAS.
Coal Industry (Patents) Ltd. (Walter T. Summers)
CA 62, 10258

299. Brit., 1,030,541 (May 25, 1966/Appl. Jan. 2, 1964)
MEASUREMENT OF GAS CONCENTRATION IN GAS MIXTURES.
Central Electricity Generating Board (Peter J. Jackson and James W. Laxton)
CA 65, 3006

300. Can., 317,948 (Dec. 15, 1931)
SEPARATION OF SULFUR DIOXIDE FROM GASEOUS MIXTURES.
(Maitland C. Boswell)
CA 26, 1728

301. Can., 335,155 (Aug. 29, 1933)
SEPARATION OF SULFUR DIOXIDE FROM GAS MIXTURES.
(Maitland C. Boswell and George P. Beal)
CA 27, 5491

302. Can., 362,537 (Dec. 15, 1936)
SULFUR DIOXIDE
American Lurgi Corp. (Conway von Girsewald, Hans Weidman, and Gerhard Roesner)
CA 31, 15632

303. Can., 375,230 (July 19, 1938)
RECOVERY OF SULFUR DIOXIDE.
(Rocco Fanelli, co-inventor)
CA 32, 7226

304. Can., 375,231 (July 19, 1938)
RECOVERY OF SULFUR DIOXIDE.
(Rocco Fanelli, co-inventor)
CA 32, 7226

305. Can., 375,232 (July 19, 1938)
RECOVERY OF SULFUR DIOXIDE.
(Rocco Fanelli, co-inventor)
CA 32, 7226

306. Can., 385,341 (Nov. 28, 1939)
RECOVERY OF SULFUR DIOXIDE FROM GASES.
Guggenheim Bros. (George H. Gleason and Alfred C. Loonam)
CA 34, 1447

307. Czech., 107,940 (July 15, 1963)
REMOVING SULFUR DIOXIDE FROM INDUSTRIAL EXHALATIONS.
(Emil Krejcar)
CA 60, 6525

308. Dan., 52,359 (Nov. 30, 1936)
COLLOIDAL SULFUR.
(Torben E. Neesby)
CA 31, 2761

309. Fr., 385,992 (Dec. 3, 1929)
SEPARATING GASES.
The Girdler Corp.
CA 24, 5898

310. Fr. 725,253 (Oct. 19, 1931)
SULFUR DIOXIDE.
Edeleanu-Ges. m. b. H.
CA 26, 4921

311. Fr., 738,747 (June 17, 1932)
PURIFYING GASES.
I. G. Farbenind. A.-G.
CA 27, 1962

312. Fr., 755,255 (Nov. 22, 1933)
SULFUR DIOXIDE.
Imperial Chemical Industries Ltd.
CA 28, 1482

313. Fr., 771,452 (Oct. 9, 1934)
RECOVERY OF SULFUR DIOXIDE.
Metallgesellschaft A.-G.
CA 29, 895

314. Fr., 46,137 (Mar 5, 1936)
SULFUR DIOXIDE RECOVERY.
Metallgesellschaft A.-G.
CA 30, 6146

315. Fr., 816,024 (July 28, 1937)
SYNTHETIC RESINS.
E. I. du Pont de Nemours & Co.
CA 32, 1356

316. Fr., 817,819 (Sept. 11, 1937)
SULFUR DIOXIDE.
Imperial Chemical Industries Ltd.
CA 32, 2301

317. Fr., 849,036 (Nov. 13, 1939)
See Brit., 523,845

318. Fr., 1,224,892 (June 28, 1960)
EXTRACTION OF SULFUR DIOXIDE FROM GASES.
Nobel-Bozel (Henri Georges Luois Marcheguet, Louis Gaudon)
CA 55, 20357

319. Fr., 1,353,646 (Feb. 28, 1964)
SULFUR DIOXIDE SEPARATION.
Nobel-Bozel (Henri G. L. Marcheguet and Louis Gaudon)
CA 61, 336

320. Fr., 1,356,116 (March 20, 1964, Span. Appl. May 3, 1962)
RECOVERY OF SULFUR DIOXIDE FROM INDUSTRIAL GASES.
Empresa Auxiliar de la Industria S. A.
CA 62, 2525

321. Fr., 1,463,790 (Dec. 30, 1966)
REMOVAL OF SULFUR COMPOUNDS AND CARBON DIOXIDE FROM FUEL GAS.
Institut Francais du Petrole, des Carburants et Lubrifiants (Phillippe Renault)
CA 67, 55941

322. Fr., 1,435,314 (Jan. 6, 1967/Fin. Appl. Jan. 25, 1965)
MANUFACTURE OF SULFUR FROM GAS CONTAINING SULFUR DIOXIDE.
Outokumpu Oy
CA 67, 66107

323. Ger. (East) 54,451 (March 5, 1967/Appl. Dec. 20, 1965)
REMOVAL OF SULFUR-CONTAINING ORGANIC COMPOUNDS FROM COKE OVEN GAS.
Gerhard Dalluege
CA 67, 56023

324. Ger., 202,349 (Mar. 7, 1907)
IN THE PRODUCTION OF SULPHUR BY THE REACTION.
Walther Feld, Zehlendorf
CA 3, 477

325. Ger., 212,902 (Jan. 9, 1907)
PROCESS OF MFG. COMPOUNDS OF ORGANIC SALTS WITH SULPHUR DIOXIDE, DEPENDENT UPON THE ACTION OF SO_2.
Farbwerke Vorm. Meister Lucius & Bruning, Hochst a/M
CA 4, 251

326. Ger., 464,010 (July 26, 1928)
DOUBLE COMPOUNDS OF SULFUR DIOXIDE WITH ALDEHYDES OR KETONES.
Rudolf Bayer Chemische Fabrik
CA 22, 4131

327. Ger., 484,836 (April 18, 1926)
AROMATIC p-DIAMINES.
I. G. Farbenind. A.-G.
CA 24, 1120

328. Ger., 506,839 (July 13, 1929)
PRODUCTS OF HYDROCARBONS AND SULFUR DIOXIDE.
Hermann Staudinger
CA 27, 522

329. Ger., 570,027 (Dec. 10, 1929)
RECOVERING SULFUR DIOXIDE FROM GAS MIXTURES BY WASHING WITH TETRAHYDRONAPHTHALENE.
F. Raschig G. m. b. H. Chem. Fab.
CA 27, 2539

330. Ger., 606,447 (Dec. 3, 1934)
SULFUR DIOXIDE.
Metallges. A.-G. (Conway Freiherr von Girsewald and Hans Weidmann, and Gerhard Roesner, inventors)
CA 29, 1594

331. Ger., 621,760 (Nov. 13, 1935)
SULFUR DIOXIDE.
Metallgesellschaft A.-G. (Conway Freiherr von Girsewald and Hans Weidmann, inventors)
CA 30, 2334

332. Ger., 623,018 (Dec. 11, 1935). Addn. to 606,447
SULFUR DIOXIDE.
Metallges. A.-G. (Conway Freiherr von Girsewald, Hans Weidmann and Gerhard Roesner, inventors)
CA 30, 2334

333. Ger., 645,879 (June 4, 1937). Addn. to 606,447
SULFUR DIOXIDE.
Metallges. A.-G. (Conway Freiherr von Girsewald, Hans Weidmann and Gerhard Roesner, inventors)
CA 31, 6425

334. Ger., 648,448 (Aug. 2, 1937)
SULFURIC ESTERS.
Chemische Fabrik R. Baumheier A.-G.
(Rudolf Kern, inventor)
CA 31, 8545

335. Ger., 660,286 (May 23, 1938)
SULFUR DIOXIDE.
Metallges. A.-G. (Conway v. Girsewald and Gerhard Roesner, inventors)
CA 32, 6408

336. Ger., 703,676 (Feb. 13, 1941)
RECOVERY OF ORGANIC BASES USED AS GAS-WASHING SOLUTIONS.
Metallgesellschaft Akt.-Ges. (Conway Freiherr von Girsewald, Gerhard Roesner and Max Wohlwill, inventors)
CA 36, 2534

337. Ger., 705,024 (March 13, 1941)
RECOVERY OF SULFUR DIOXIDE.
Edeleanu-Gesellschaft m. b. H. (Alfred Hoppe, inventor)
CA 36, 2095

338. Ger., 706,833 (May 8, 1941)
REMOVING SULFUR DIOXIDE FROM GASES.
Rocco Fanelli and Raymond F. Bacon (to Raymond F. Bacon)
CA 37, 2547

339. Ger., 707,132 (May 15, 1941)
RECLAIMING SULFUR FROM GASES.
Metallgesellschaft Akt.-Ges. (Max Wohlwill, inventor)
CA 36, 2099

340. Ger., 711,821 (Sept. 11, 1941)
ORGANIC SULFUR COMPOUNDS.
I. G. Farbenind. A.-G. (Friedrich Asinger, inventor)
CA 37, 4405

341. Ger., 715,846 (Dec. 4, 1941)
ORGANIC SULFUR COMPOUNDS.
I. G. Farbenind. A.-G. (Paul Herold, Karl Smeykal, Friedrich Asinger and Horst Dietrich Frhr. von der Horst, inventors)
CA 38, 2050

342. Ger., 719,059 (March 5, 1942)
ORGANIC COMPOUNDS CONTAINING SULFUR.
I. G. Farbenindustrie A.-G.
(Horst-Dietrich Freiherr v. der Horst, inventors)
CA 37, 1722

343. Ger., 721,892 (May 14, 1942)
ORGANIC SULFUR COMPOUNDS.
I. G. Farbenind. A.-G.
(K. Smeykal and R. Kuhn, inventors)
CA 37, 5417

344. Ger., 725,800 (Aug. 13, 1942)
ORGANIC S COMPOUNDS.
I. G. Farbenind. A.-G. (Friedrich Asinger, inventor)
CA 37, 5984

345. Ger., 728,223 (Oct 22, 1942). Addn. to Ger., 715,846
ORGANIC SULFUR COMPOUNDS.
I. G. Farbenind. A.-G.
(Karl Smeykal, Horst Dietrich Frhr. von der Horst and Georg Peinze, inventors)
CA 37, 5984

346. Ger., 737,031 (May 27, 1943)
GAS WASHING.
Heinrich Koppers G. m. b. H. (Alfred Karl, inventor)
CA 38, 3803

347. Ger., 742,741 (October 21, 1943)
ORGANIC SULFUR COMPOUNDS.
I. G. Farbenind. A.-G.
(Walter Reppe, August Spaeth, and Hans Krzikalla, inventors)
CA 40, 1169

348. Ger., 950,951 (Oct. 18, 1956)
GAS PURIFICATION
Karl Fehr
CA 53, 12641

349. Ger., 952,892 (Nov. 22, 1958)
ABSORPTION OF SULFUR DIOXIDE FROM GASES.
Metallgesellschaft Akt. -Ges.
(Wilhelm Thumm, Ernst Wegener, Gerhard Roener, and Josef Harwasser, inventors)
CA 53, 4705

350. Ger., 1,025,400 (Mar. 6, 1958)
RECOVERY OF SULFUR DIOXIDE FROM GAS MIXTURES.
Metallgesellschaft Akt. -Ges.
(Wilhelm Thumm, inventor)
CA 54, 13611

351. Ger., 1,098,922 (Feb. 9, 1961)
SULFUR DIOXIDE MAKE-UP FOR SULFITE PULP.
Metallgesellschaft Akt. -Ges. (Wilhelm Thumon, inventor)
CA 55, 26443

352. Ger., 1,118,168 (Nov. 30, 1961 Span. Appl. April 12, 1958)
RECOVERY OF PURE SULFUR FROM SULFUR DIOXIDE-CONTAINING GASES.
Instituto Nacional de Industria (Angel Vian Orturo, inventor)
CA 56, 11232

353. Ger., 1,166,751 (April 2, 1964)
REMOVAL OF HYDROGEN SULFIDE AND SULFUR DIOXIDE FROM EXHAUST GASES.
Aktiengesellschaft fuer Chemische Industrie
(Manfred Mueller, inventor)
CA 61, 1534

354. Ger., 1,222,048 (Aug. 4, 1966, Appl. Dec. 8, 1964)
SULFONES AND POLYSULFONES BY REACTION OF SO_2 AND ACRYLIC COMPOUNDS.
Farbenfabriken Bayer A. -G. (Kuno Wagner, inventor)
CA 65, 13545

355. Hung., 126,899 (May 15, 1941)
SEPARATION OF SULFUR DIOXIDE FROM GAS MIXTURES.
Jeno Pap.
CA 35, 7665

356. Japan, 172,814 (May 31, 1946)
RECOVERING OF SULFUR DIOXIDE
Furukawa Kogyo K. K. (Tamaki Nakazono, inventor)
CA 43, 7201

357. Neth. Appl, 6,506,804 (Nov. 29, 1966, Appl. May 28, 1965)
TRIMETHYLAMINE-SULFUR TRIOXIDE COMPLEX.
Baldwin-Montrose Chemical Co.
CA 67, 85456

358. Neth. Appl., 6,613,112 (March 20, 1967), Fr. Appl. Sept. 18, 1965
WASHING OF SULFUR-CONTAINING GASES.
Institut Francais du Petrole, des Carburants et Lubrifiants
CA 67, 75127

359. Span., 261,844, Appl. Oct. 20, 1960
RECUPERATION OF SULFUR DIOXIDE FROM INDUSTRIAL GASES OF ANY CONCENTRATION.
Empresa Auxiliar de la Industria, S. A. (Angel Vian Ortune, inventor)
CA 56, 11232

360. Swed. 124,600 (April 12, 1949)
SEPARATING GASES IN MIXTURES.
A. R. Persson, J. O. Naucler
CA 43, 8758

361. Swed., 126,527 (Oct. 25, 1949)
CONCENTRATING GASES CONTAINING SULFUR DIOXIDE.
Aktiebolaget Kaukas Fabrik (V. H. Somer, T. E. Brehmer, inventors)
CA 44, 3684 and 3712

362. U. S., 927,342 (July 6)
RECOVERY OF SULPHUR FROM GAS.
Walther Feld, Zeklendorf, and Anton Jahl, Honninger, A. R.
CA 3, 2354

363. U. S., 1,260,492 (Mar. 26)
RECOVERING SULFUR DIOXIDE FROM FURNACE GASES.
U. Wedge and F. A. Eustis
CA 12, 1499

364. U. S. 1,315,189 (Sept. 2)
RECOVERING SULFUR DIOXIDE FROM COMBUSTION GASES.
H. K. Moore and G. A. Richter
CA 13, 2747

365. U. S. 1,398,791 (Nov. 29)
ABSORPTION OF SULFUR DIOXIDE.
P. Pascal
CA 16, 800

366. U. S. 1,726,252 (Aug. 27)
COMPLEX COMPOUNDS OF AROMATIC ρ-DIAMINES WITH SULFUR DIOXIDE.
I. G. Farbenind. A.-G. (Richard Wolffenstein, inventor)
CA 23, 4949

367. U. S., 1,834,016 (Dec. 1)
SEPARATING ACIDIC GASES.
The Girdler Co. (Robert R. Bottoms, inventor)
CA 26, 1046

368. U. S., 1,910,341 (May 23)
SEPARATING SULFUR DIOXIDE FROM LIQUID HYDROCARBONS.
Edeleanu G. m. b. H. (Paul Jodeck, inventor)
CA 27, 4069

369. U. S., 1,946,489 (Feb. 13)
RECOVERY OF GASES SUCH AS SULFUR DIOXIDE FROM DILUTE MIXTURES SUCH AS SMELTER GASES.
Fredrik W. de Jahn (to Jacob D. Jenssen)
CA 28, 2433

370. U. S., 1,951,992 (March 20)
SEPARATING ACID GASES FROM GASEOUS MIXTURES.
Carbide & Carbon Chemicals Corp. (Granville A. Perkins, inventor)
CA 28, 3564

371. U. S., 1,954,959 (April 17)
FREEING HYDROCARBON OILS FROM SULFUR DIOXIDE.
Standard Oil Development Co.
(Reginald K. Stratford and William P. Doohan, inventor)
CA 28, 3887

372. U. S., 1,972,074 (Sept. 4)
SEPARATING SULFUR DIOXIDE FROM GASEOUS MIXTURES.
Maitland C. Boswell
CA 28, 6536

373. U. S., 2,082,006 (June 1)
REMOVING AND RECOVERING SULFUR DIOXIDE FROM WASTE GASES.
Board of Trustees of the Univ. of Ill.
(Henry F. Johnstone, inventor)
CA 31, 5139

374. U. S., 2,106,435 (Jan. 25)
REMOVING ACIDIC GASES FROM GASEOUS MIXTURES SUCH AS AIR OR HYDROGEN.
Robinson Bros. Ltd.
(Deric W. Parkes and Richard B. Evans, inventors)
CA 32, 2719

375. U. S., 2,112,986 (Apr. 5)
RESINOUS REACTION PRODUCTS.
Phillips Petroleum Co. (Frederick E. Frey and Robert D. Snow, inventors)
CA 32, 3858

376. U. S., 2,128,027 (Aug. 23)
RECOVERY OF SULFUR DIOXIDE FROM GAS MIXTURES.
Imperial Chemical Industries Ltd. (Arthur M. Clark, inventor)
CA 32, 8087

377. U. S., 2,134,481 (Oct. 25)
RECOVERING SULFUR DIOXIDE FROM WASTE GASES SUCH AS BOILER AND FURNACE GASES.
Commonwealth Edison Co. (Henry F. Johnstone, inventor)
CA 33, 1110

378. U. S., 2,139,375 (Dec. 6)
REMOVAL OF SO_2 FROM GASES SUCH AS NITROGEN.
Shell Development Co.
(Russell W. Millar and Herbert P. A. Groll, inventor)
CA 33, 2293

379. U. S., 2,142,987 (Jan. 10)
SULFUR DIOXIDE RECOVERY FROM GASES SUCH AS THOSE FROM ORE ROASTING.
Raymond F. Bacon and Rocco Fanelli (to Raymond F. Bacon)
CA 33, 3082

380. U. S., 2,174,111 (Sept. 26)
TREATING BENZENE WITH CHLORINE AND SULFUR DIOXIDE, AND SIMILAR REACTIONS.
Cortes F. Reed (50% to Charles L. Horn)
CA 34, 4535

381. U. S., 2,185,311 (Jan. 2)
RECOVERY OF SOLVENTS SUCH AS SULFUR DIOXIDE AND BENZENE USED FOR TREATING LUBRICATING OILS.
Union Oil Co. of Calif.
(Edward G. Ragatz and Donald E. McFaddin, inventors)
CA 34, 3074

382. U. S., 2,186,453 (Jan. 9)
SULFUR DIOXIDE RECOVERY FROM GASES.
Guggenheim Bros. (Geo. H. Gleason and Alfred C. Loonam, inventors)
CA 34, 3455

383. U. S., 2,192,461 (Mar. 5)
SULFUR DIOXIDE RECOVERY FROM GASES SUCH AS RESIDUAL ROASTING-FURNACE GASES.
American Lurgi Corp. (Conway Baron von Girsewald, Gerhard Roesner and Max Wohlwill, inventors)
CA 34, 4529

384. U. S., 2,228,598 (Jan. 14)
PURIFICATION OF HYDROCARBON-SULFUR DIOXIDE-CHLORINE REACTION PRODUCTS.
(Arthur L. Fox, Clyde O. Henke and Cortes F. Reed, inventors)
E. I. du Pont de Nemours & Co. (Fox and Henke)
Charles L. Horn (Reed one-sixth)
CA 35, 3011

385. U. S., 2,270,490 (Jan. 20)
MORPHOLINE COMPOUNDS.
Harris-Seybold-Potter Co. (Wm. H. Wood, inventor)
CA 36, 3298

386. U. S., 2,295,587 (Sept. 15)
RECOVERY OF SULFUR DIOXIDE FROM GAS MIXTURES SUCH AS SMELTER SMOKE.
American Smelting and Refining Co.
(Edward P. Fleming and T. Cleon Fitt, inventors)
CA 37, 1234

387. U. S., 2,301,779 (Nov. 10)
SEPARATE RECOVERY OF HYDROGEN CHLORIDE AND SULFUR DIOXIDE FROM GAS MIXTURES SUCH AS THOSE FROM HYDROCARBON-OIL TREATMENT.
Alien Property Custodian (Paul Herold and Georg Markus, inventors)
CA 37, 2145

388. U. S., 2,368,545 (Jan. 30, 1945)
RECOVERY OF SULFUR DIOXIDE FROM MIXTURES WITH OTHER GASES OR WITH LOW-BOILING HYDROCARBONS.
The Dow Chemical Co.
(George W. Hooker, Lewis R. Drake, and Stephen C. Stowe, inventors)
CA 39, 5421

389. U. S., 2,368,595 (Jan. 30, 1945)
SCRUBBING OF GASEOUS HYDROCARBONS CONTAINING H_2S, CO_2, SO_2 AND THE LIKE.
Shell Development Co. (Ava J. Johnson, inventor)
CA 39, 5440

390. U. S., 2,368,600 (Jan. 30, 1945)
PURIFICATION OF GASES AND SEPARATION OF ABSORBED IMPURITIES.
Shell Development Co. (Ludwig Rosenstein, inventor)
CA 39, 5440

391. U. S., 2,370,020 (Feb. 20, 1945)
SEPARATION OF SULFUR DIOXIDE FROM GASES.
Union Oil Co. of California (Thomas F. Doumani, inventor)
CA 39, 5072

392. U. S., 2,381,257 (Aug. 7, 1945)
ADDITION COMPOUND OF SULFUR DIOXIDE WITH ANOTHER INSECTICIDE AND METHOD OF DISPENSING AN INSECTICIDE.
Frank L. Campbell and W. Conard Fernelius
CA 40, 163

393. U. S., 2,384,376 (Sept. 4, 1945)
RECOVERY OF SULFUR DIOXIDE AND DIOLEFINS FROM SULFONES.
Dow Chemical Co. (Geo. M. Hebbard, inventor)
CA 40, 344

394. U. S., 2,334,378 (Sept. 4, 1945)
SEPARATION OF SULFUR DIOXIDE AND LOW-BOILING HYDROCARBONS.
Dow Chemical Co.
(George W. Hooker and Franc A. Landee, inventors)
CA 40, 718

395. U. S., 2,385,704 (Sept. 25, 1945)
RECOVERING SULFUR DIOXIDE.
The Dow Chemical Co.
(George W. Hooker, Stephen C. Stowe, and Lewis R. Drake, inventors)
CA 40, 185

396. U. S., 2,395,050 (Feb. 19, 1946)
SEPARATION OF 1,3-BUTADIENE FROM MIXTURES BY USING SULFUR DIOXIDE.
Dow Chemical Co. (George W. Hooker, Lewis R. Drake, and Stephen C. Stowe, inventors)
CA 40, 3124

397. U. S., 2,395,278 (Feb. 19, 1946)
TREATMENT OF ABIETYL COMPOUNDS WITH SULFUR DIOXIDE.
Ridbo Laboratories, Inc. (Nicholas L. Kalman, inventor)
CA 40, 3137

398. U. S., 2,399,013 (Apr. 23, 1946)
SULFUR DIOXIDE RECOVERY.
American Smelting and Refining Co.
(Edward P. Fleming and T. Cleon Fitt, inventors)
CA 40, 7538

399. U. S., 2,403,319 (July 2, 1946)
HYDROGEN SULFIDE REMOVAL FROM GASES.
Standard Oil Development Co. (Milton Williams, inventor)
CA 40, 5549

400. U. S., 2,404,854 (July 30, 1946)
REGENERATION OF ABSORBENT.
Phillips Petroleum Co.
(John W. Latchum, Jr., and James S. Connors, inventors)
CA 40, 6230

401. U. S., 2,539,871 (Jan. 30, 1951)
SOLUTIONS OF GASES.
Aktiebolaget Centrallaboratorium (T. H. Smedslund, inventor)
CA 45, 4497

402. U. S., 2,676,872 (Apr. 27, 1954)
GLYCOL SULFITE IN HANDLING OF SULFUR DIOXIDE.
Societe Anon. des Manufactures des Glaces et Produits Chimiques de Saint-Gobain, Chauny & Circy
(Marcel J. Viard, inventor)
CA 48, 11018

403. U. S., 3,023,088 (Feb. 27, 1962)
SULFUR.
Universal Oil Products Co.
(Peter Urban, and Lester G. Massey, inventors)
CA 56, 13796

404. U. S., 3,183,145 (May 11, 1965)
ODOR CONTROL AND HEAT RECOVERY IN WOOD PULPING.
Theron T. Collins, Jr.
CA 64, 6892

405. U. S., 3,226,430 (Cl. 260-501)(Dec. 28, 1965, Appl. Feb. 26, 1962 and April 7, 1964)
CYCLOHEXYLAMINE CYCLOHEXYLSULFAMATE.
Abbott Laboratories (Madhukar V. Mhatre, inventor)
CA 64, 8054

406. U. S., 3,287,389 (Nov. 22, 1966, Appl. Sept. 14, 1962)
COMPLEXES OF SO_3 WITH NITRILES.
Monsanto Co. (George L. Broussalian, inventor)
CA 67, 37459

407. U. S., 3,346,505 (Oct. 10, 1967, Appl. March 15, 1963)
SULFONATION OF ORGANIC COMPOUNDS.
Colgate-Palmolive Co.
(John M. Blakeway and Philip Marshall, inventors)
CA 68, 77976

408. U. S., 3,350,470 (Oct. 31, 1967, Appl. Dec. 1, 1961)
LIQUID-LIQUID EXTRACTION PROCESS.
Union Oil Co. of California (Art C. McKinnis, inventor)
CA 68, 51847

409. U. S., 3,363,939 (Jan. 16, 1968, Appl. Nov. 4, 1965)
REMOVAL OF SULFUR-CONTAINING GASES FROM GASEOUS MIXTURES.
Shell Oil Co.
(Carl H. Deal, Jr., and Michael N. Papadopoulos, inventors)
CA 68, 61410

410. Brit. 708,095 (April 28, 1954)
REMOVAL OF SULFUR OXIDES FROM FLUE GASES AND THEIR CONVERSION TO AMMONIUM SULFATE.
Walter G. Lowenstein-Lom (to Standard Oil Development Co.).
CA 48: 11033^a (1954)

411. Brit. 744,465 (Feb. 8, 1956)
WASHING AND COOLING OF GASES CONTAINING SULFUR DIOXIDE.
Chemiebau Dr. A. Zieren G.m.b.H.
CA 50: 13411 (1956)

412. Can. 410,409 (Feb. 2, 1943)
RECOVERY OF SULFUR DIOXIDE FROM DIGESTER GASES.
Horace A. DuBois (to Paper Patents Co.).
CA 37: 2183^1 (L)

413. Ger. 679,709 (Aug. 12, 1939)(Cl. 12e. 5).
ELECTROFILTER FOR PURIFYING GASES.
I. G. Farbenind. A.-G.
CA 33: 9160^6 (L)

414. U.S. 2,137,311 (Nov. 22)
SULFUR DIOXIDE RECOVERY FROM SULFITE LIQUORS.
Karl L. Springer (to Standard Oil Development Co.).
CA 33: 1892^1 (L)

415. U.S. 2,173,877 (Sept. 26)
SULFUR DIOXIDE RECOVERY FROM GAS MIXTURES, SUCH AS THOSE FROM ORE ROASTING.
Arthur M. Clark, William E. Batten and Charles F. R. Harrison (to Imperial Chemical Industries Ltd.).
CA 34: 594^8 (L)

416. U.S. 2,180,495 (Nov. 21)
RECOVERY OF SULFUR DIOXIDE FROM GASES.
Raymond F. Bacon
CA 34: 1826^t

417. U.S. 2,676,090 (April 20, 1954)
RECOVERY OF SULFUR DIOXIDE FROM WASTE GASES.
Henry F. Johnstone (to Texas Gulf Sulphur Co.).
CA 48: 11018b (1954)

418. U.S. 2,718,453 (Sept. 20, 1955)
DESULFURIZATION OF FLUE GASES.
John W. Beckman.
CA 50: 1292c (1956)